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PAPERS IN PRESS FOR FORTHCOMING ISSUES

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GEOLOGY OF THE TECOPA AREA, SOUTHEASTERN CALIFORNIA. By John Mason

This paper is accompanied by a colored geologic map of the area. Separate copies of the map, unfolded and in tubes, may be secured. Price 25 cents apiece. **Orders should be accompanied by remittance.**

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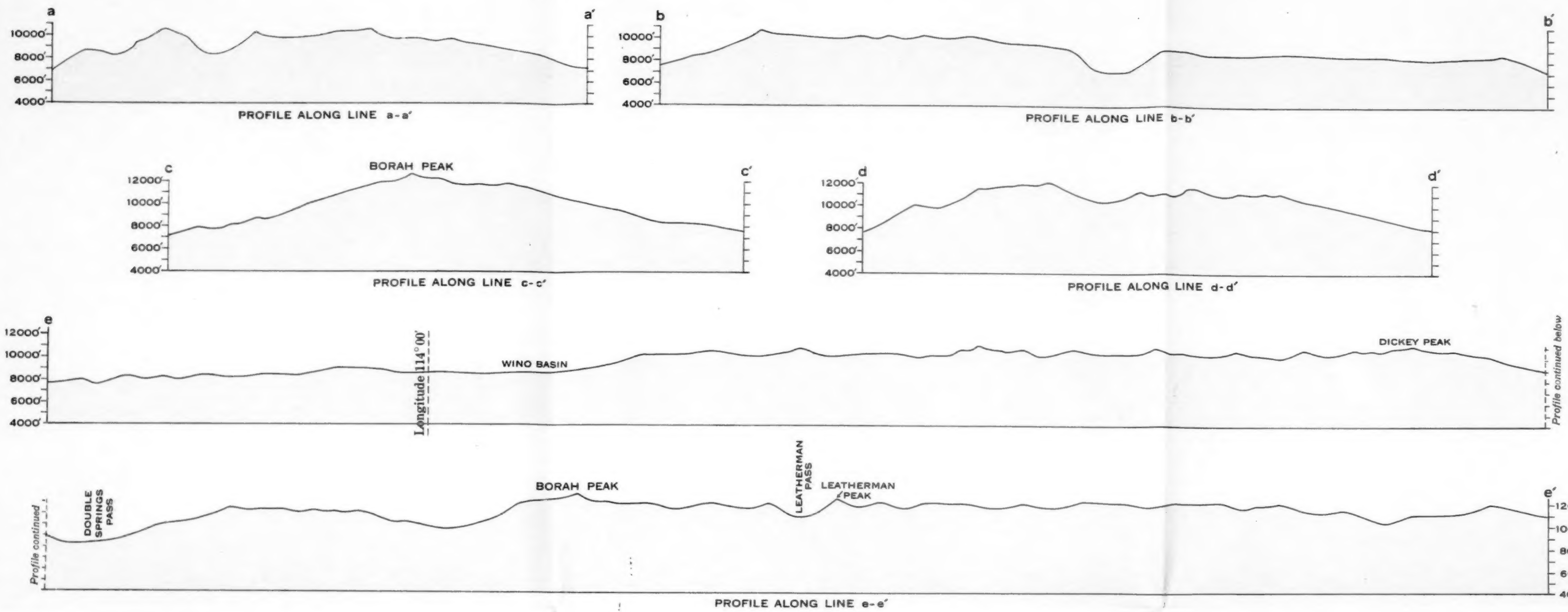

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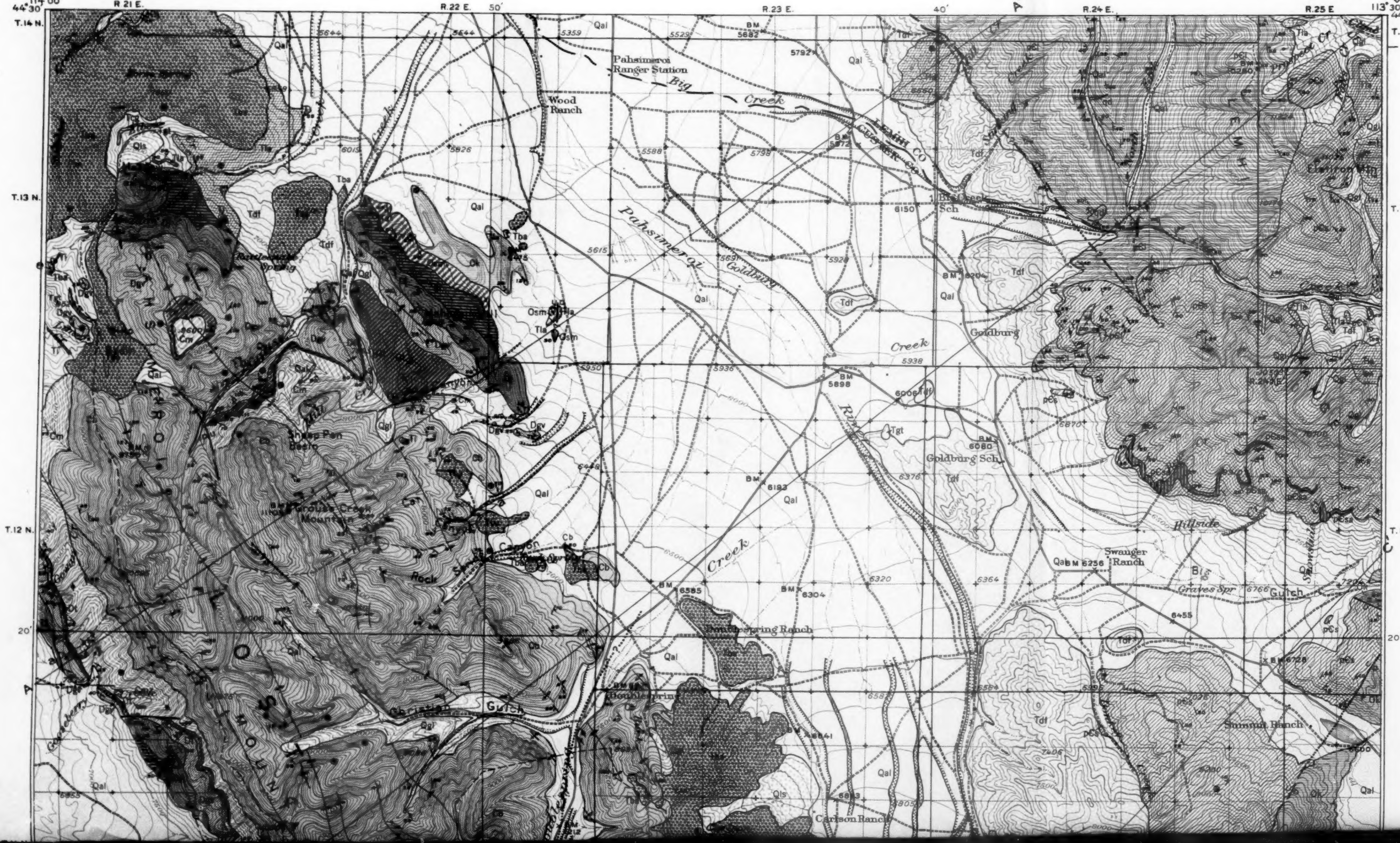


EXPLANATION

QUATERNARY

Recent

Qal Qt — **Alluvium**
(Fan and stream deposits with a little travertine (Qt) along some streamways)

Qls — **Landslides**

Pleistocene

Qgl — **Glacial deposits**
(Mostly moraines and glacial outwash in which original form is still recognizable)

TERTIARY

Tdf — **Donkey fanglomerate**
(Old, somewhat consolidated alluvial deposits)

UNCONFORMITY

Ti — **Basalt and andesite intrusions associated with the Challis volcanics**

Late Oligocene or early Miocene — *Challis volcanics*

Tba — **Basalt**
(Flows of dark basalt and calcic andesite at different horizons)

Tgt Tcg — **Germer tuffaceous member**
(Mainly light-colored tuff, which locally is distinctly bedded; intercalated conglomerate (Tcg) is mapped separately where scale permits)

Tla — **Latite-andesite member**
(Flows and pyroclastics, mainly of intermediate composition)

MESOZOIC

qd — **Quartz diorite**

la — **Lamprophyre**

UNCONFORMITY

CARBONIFEROUS

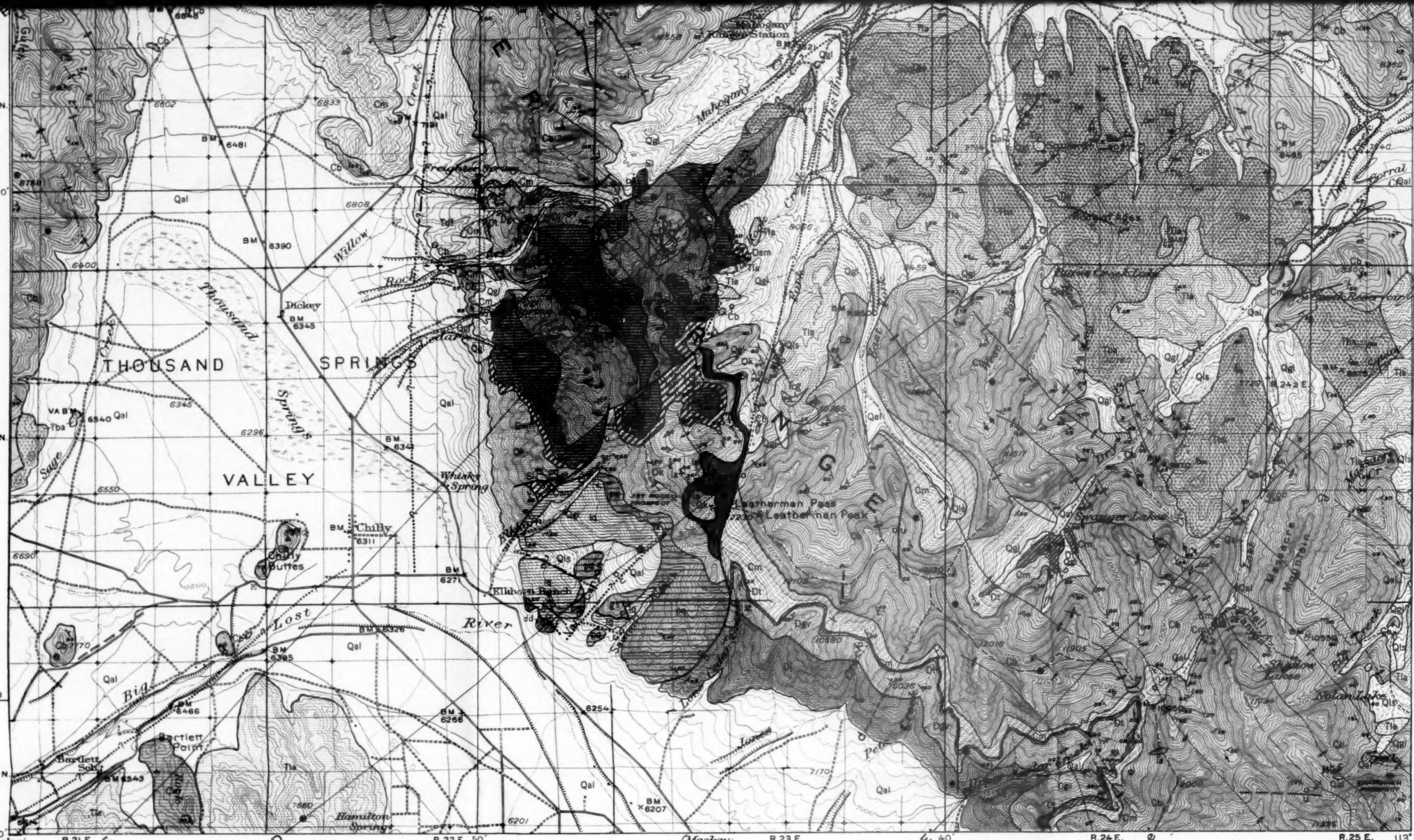
Pennsylvanian

Cwr — **Wood River formation**
(Mainly dark, impure quartzite)

Mississippian

Cb — **Brazer limestone**
(Well-bedded to massive limestone; in part slightly dolomitic; contains some chert)

Cm — **Milligen formation**
(Mainly carbonaceous argillite, locally some quartzitic and calcareous beds)



Geologic cartography by Porter L. Mattox

Map Drafted in Cooperation with U. S. Geological Survey

GEOLOGIC MAP OF THE BORAH PEAK QUADRANGLE, IDAHO

WITH STRUCTURE SECTIONS

by Clyde P. Ross

APPROXIMATE MEAN DECLINATION 1935

Scale $\frac{1}{125000}$

Contour interval 100 feet.

Datum is mean sea level.

1947

(Moderately light-colored dolomite with some quartzitic beds, mainly near base)

SILURIAN

Upper Ordovician

Osm — **Saturday Mountain formation**
(Moderately dark dolomite with some shaly and siliceous beds, especially near the base)

Ok — **Kinnikinic quartzite**
(Mainly light-colored quartzite with some interbedded dolomite and shales)

ORDOVICIAN

Ordovician or older — Rocks near Sawmill Gulch (Stratigraphic relations only partly determined)

pq — **Purple quartzite**
(Includes purple and lavender quartzite, locally with pebbles)

gs — **Slate**
(Mostly laminated green and purplish slate)

sd — **Dolomite**
(Dark, siliceous dolomite. Only the larger masses are shown)

lq — **White and light colored quartzite**
(Includes quartzite that resembles the Kinnikinic and darker beds with pebbles. Some other rocks are locally grouped with these)

UNCONFORMITY

Belt series

p€s — **Swauger quartzite**
(Rather pure quartzite, mostly lavender and paler in color, with argillaceous beds (p€sa) in places)

p€l — **Lemhi quartzite**
(Mainly greenish impure quartzite)

PRE-CAMBRIAN

Normal fault
U, *Upthrown side*
D, *Downthrown side*

Inferred normal fault

Thrust fault
T, *Overthrust side*

Fault breccia
(Composed of Kinnikinic and later rocks)

Strike and dip of beds

Strike of vertical beds

Strike and dip of overturned beds

Horizontal beds

Axis of anticline

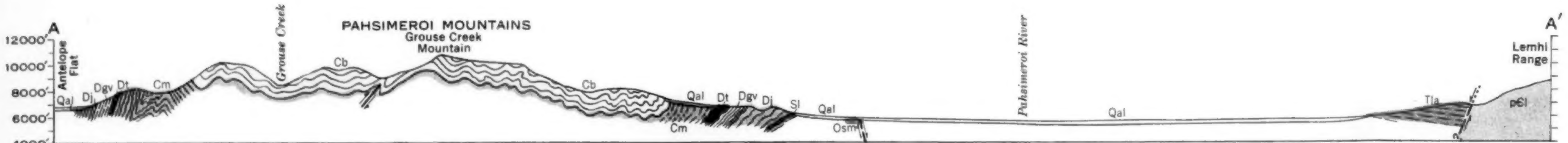
Axis of overturned anticline

Axis of overturned anticline broken by thrust fault

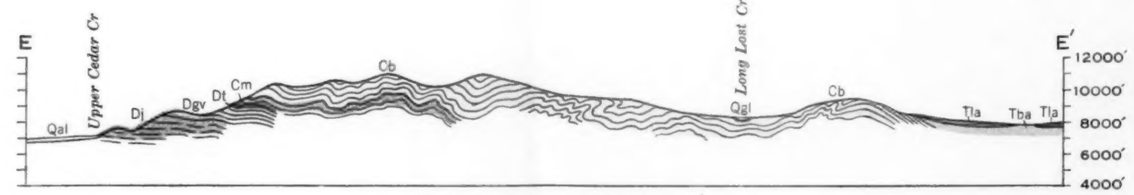
Line of topographic profile shown on plate 2

Line of geologic section

Terrace



SECTION ALONG LINE A-A'



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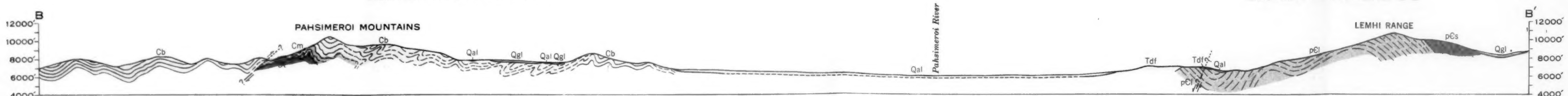
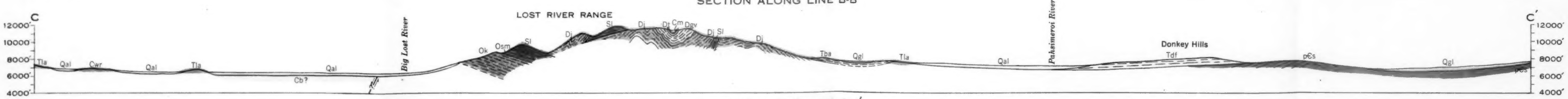


SECTION ALONG LINE B-B'



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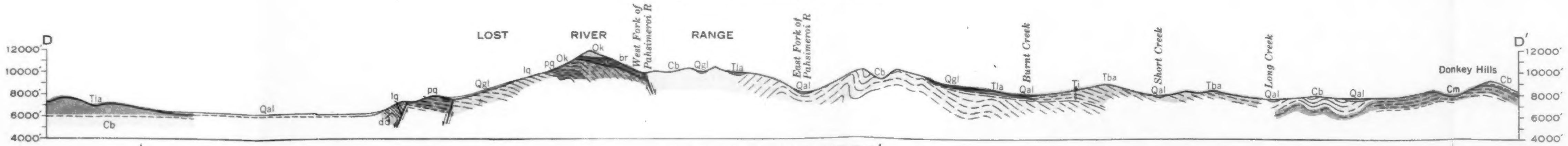


SECTION ALONG LINE D-D'

Abs
Intr

Top

Stra

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 58, 13 PLS., 6 FIGS., PP. 1085-1160 DECEMBER 1947

GEOLOGY OF THE BORAH PEAK QUADRANGLE, IDAHO

BY CLYDE P. ROSS

CONTENTS

ILLUSTRATIONS

ABSTRACT

This report is one result of a long program of geologic investigation in south-central Idaho, undertaken as an aid in the development of the mineral resources of the region. This quadrangle was examined because of the exceptional opportunities for the study of stratigraphy and structure afforded by the Lost River Range, which is the highest in Idaho and contains comparatively few intrusive igneous rocks.

The Borah Peak quadrangle differs from the region to the west and northwest in that it contains parts of two sharply defined, narrow ranges elongated in a northwesterly direction, instead of broad, irregular mountain masses, in which the trends of most local topographic units are ill-defined. These ranges, the Lost River and the Lemhi, are flanked by intermontane valleys sparsely populated by stock ranchers.

The Lemhi and Swauger quartzites, regarded as of Belt (pre-Cambrian) age, are named. The two Cambrian (?) formations of the Bayhorse region are not recognized in this quadrangle. The Ramshorn slate (Lower Ordovician), widespread and thick there, does not appear to be exposed anywhere in the Borah Peak quadrangle with the possible exception of small areas east of the Elkhorn Ranch, where relations are obscure. The higher Paleozoic formations, named in order of decreasing age, are the Kinnikinic quartzite, Saturday Mountain formation, Laketown dolomite, Jefferson dolomite, Grand View dolomite, Three Forks limestone, Milligen formation, Brazer limestone, and Wood River formation. The Three Forks limestone, nowhere much over 250 feet thick, is the only one of these not recognized farther west. It provides substantial aid in the interpretation of upper Paleozoic stratigraphy. Equivalent beds to the west are presumably grouped with the Milligen. The grit that introduced uncertainties into the correlation of the Wood River and Milligen formations in the southeastern part of the Bayhorse quadrangle is absent here, and both formations have close lithologic resemblances to those in the type localities in the Wood River region. Wood River strata (Pennsylvanian) crop out only in the southwest corner of the quadrangle, and the Brazer may have been the last Paleozoic unit to be deposited over most of the area. Certainly it can have had comparatively little cover over it throughout the Mesozoic. The Brazer is regarded as Mississippian, but some of the fossils in it have Pennsylvania affinities. The carbonate rocks in the Three Forks and later formations are dominantly calcareous, while those in earlier units are dolomitic. Carbonaceous matter is present in most of the formations but is abundant only in the Milligen.

The Challis volcanics (Oligocene or Miocene) constitute the first stratified unit to be laid down after Paleozoic deposition ceased, although there was a little intrusive activity late in the Mesozoic. The volcanics were once widely distributed on the flanks of the mountains and are still plentiful in the northwestern corner of the quadrangle, near the head of the valley of the Pahsimeroi, and in smaller areas. They are neither so abundant nor so diversified as they are farther west. They are locally succeeded by an alluvial formation, here termed the Donkey fanglomerate, of possible Pliocene age. Abundant Quaternary glacial and alluvial deposits are present in the larger valleys.

The Lemhi and Swauger quartzites were broadly folded before Paleozoic sedimentation began. Apparently the later deformation affected them only enough to render the more impure beds somewhat schistose. The Paleozoic rocks have been folded

into closely spaced, asymmetric anticlines, locally broken by thrusts at and near their crests. These folds approximately parallel the trends of the present range, whereas those in the old rocks strike more nearly north. Later deformation twisted some of the folds and produced thrusts of lower dip and greater extent. The folded rocks in the Lost River Range have been arched into an anticlinorium. The original, tight folds may have preceded the emplacement of the Idaho batholith farther west, while the anticlinorium and the late twists and low thrusts result from deformation during the long period in which the batholith came to place and adjusted itself. Local intricately contorted beds in the Brazer limestone are interpreted as the effects of flowage in calcareous material subjected to tangential pressure under comparatively light supercumbent load.

The quadrangle contains numerous normal faults of diverse trends. Most of those that can be conclusively demonstrated strike transverse to the trends of the ranges, but especially along parts of the southwest front of the Lemhi Range normal faults along the range fronts may have helped locally to guide erosion of the mountains. Some of the faults have displacements of thousands of feet and are thought to have originated in connection with the low-angle thrusts. Most of these, as well as minor breaks of diverse trends, affect also the Challis volcanics, which shows that renewed movement occurred in Tertiary time.

The present mountain masses and broad intermontane valleys are in about the positions occupied by similar features in the early Tertiary. Several incomplete erosion cycles since then have greatly modified the topography but have not obliterated the influence of these ancient land forms. The results of early episodes in the development of the topography are much obscured by the rugged forms that result from active Pleistocene glaciation and later vigorous stream erosion, but modified remnants of the post-Challis and Donkey Hills surfaces can be clearly distinguished. Several less widespread remnants mark intermediate steps in the process. Exceptionally abundant and permeable, coarse alluvial and glacial deposits floor intermontane valleys and choke the larger mountain gorges to such an extent as to interfere with normal erosion and make the surface-water supplies even scantier than might be expected from the climate of the region, which is moderately humid in the mountains and semiarid in the valleys. Active erosion in the high mountains and comparatively static conditions on fans at the range borders result in striking contrasts.

INTRODUCTION

LOCATION

The Borah Peak quadrangle lies mainly in the eastern part of Custer County, Idaho, but its northeastern corner extends into Lemhi County. Most of the mountainous part of the quadrangle is included in the Challis National Forest, but a small area belongs to the Salmon National Forest. The quadrangle has an area of 856.7 square miles and is bounded by meridians 113°30′ and 114° and parallels 44° and 44°30′ (Fig. 1).

PURPOSE AND SCOPE OF THE REPORT

The present work marks a resumption, beginning in 1935, of a study of the geology of south-central Idaho carried on by the writer almost without interruption from 1923 to 1931 inclusive. The comparative lack of igneous metamorphism and of the obscuring local complexities generally associated with ore deposits led to the hope that data might be obtained in regard to some of the problems of stratigraphic relations and of structure that have arisen in the course of study of neighboring areas (Fig. 1). This hope, which constituted the main reason for the study of the quadrangle, has

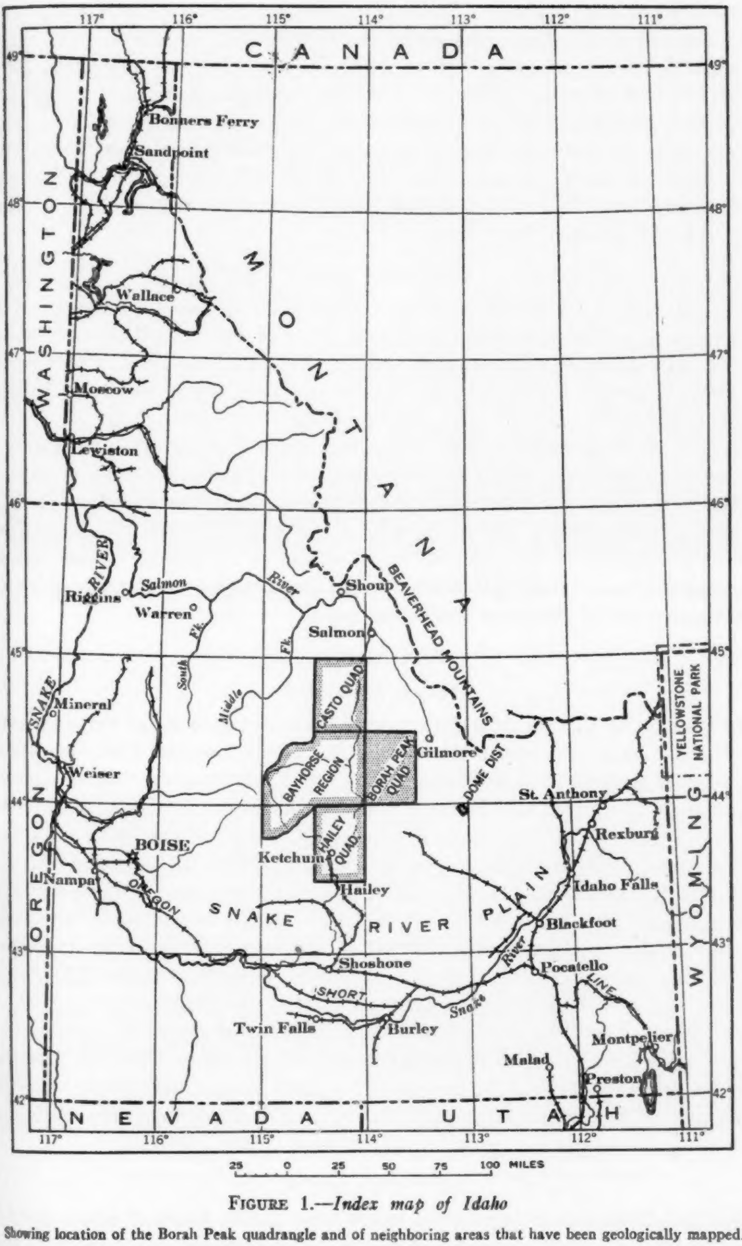


FIGURE 1.—*Index map of Idaho*

Showing location of the Borah Peak quadrangle and of neighboring areas that have been geologically mapped.

in some measure, been realized. The broader questions as to the stratigraphy of the Carboniferous and Devonian rocks can now be answered with considerable assurance, and available information regarding the older rocks has also been increased. Here, as elsewhere in south-central Idaho, there are marked local variations in stratigraphy so that new problems are presented, particularly as to certain metamorphosed rocks, exposed in limited areas, that may be of early Ordovician age. The intricate structural features of the quadrangle, some of which are still incompletely understood, record deformation in at least four periods and add confidence to previous deductions in regard to the history of the region.

ACKNOWLEDGMENTS

The field work in the Borah Peak quadrangle occupied about 2 months in 1935 and 3 months in 1936 with brief revisits in 1937 and 1938. In 1935 Charles Lee afforded able assistance in the geologic work, and in 1936 Newton E. Chute served in a similar capacity. The work of both seasons was greatly facilitated by conscientious and skillful management of the pack train by Marion Peel.

James S. Williams devoted considerable time in both seasons to examination of the Carboniferous strata in and near the Borah Peak quadrangle and aided also in the collection of fossils in older beds. These paleontologic data have been of indispensable aid in the study of the quadrangle. G. R. Mansfield visited the area during the field season of 1936, and his detailed knowledge of the geology of southeastern Idaho enabled him to make instructive comparisons between the stratigraphic units of that region and of the Borah Peak quadrangle.

TOPOGRAPHY

GENERAL STATEMENT

The Borah Peak quadrangle is distinguished from the region to the west and northwest in that it is in the comparatively small part of south-central Idaho marked by long, narrow, subparallel ranges separated by broad intermontane valleys—features characteristic of southeastern Idaho. They are in sharp contrast to the irregular mountain masses that occupy most of the central portion of the State. The Lost River Range extends diagonally across the quadrangle, with the Donkey Hills and a small portion of the Lemhi Range included in the northeast part of the quadrangle. Small parts of other mountain masses enter the quadrangle near its southwest corner. Thousand Springs Valley and the upper part of Pahsimeroi Valley comprise the lower areas within the quadrangle. Both are traversed by numerous roads; the principal ones are shown on Plate 1. Most drainage of the quadrangle is tributary to the Salmon River, mainly through the Pahsimeroi River. The southwestern and southeastern corners, however, drain toward the Snake River Plain through the Big and Little Lost rivers. Much of the drainage throughout the quadrangle is underground largely because of the abundant alluvial deposits. The small amounts of water that reach the main valleys in streams are largely used up by irrigation.

LOST RIVER RANGE

The Lost River Range has a total length of about 85 miles, of which about 36 miles, trending N. 35° W., is included within this quadrangle. It is about 15 miles

FIGURE 1. CREST OF PAHSIMEROI MOUNTAINS
View south from near northeast corner of sec. 3, T. 11N., R.21E., showing one of the buttresses that are distinctive features of this part of the range.

FIGURE 2. THOUSAND SPRINGS VALLEY FROM BIRCH SPRING
Lines of vegetation mark channels of Cedar Creek and smaller streams.

VIEWS IN THE PAHSIMEROI MOUNTAINS AND THOUSAND SPRINGS VALLEY

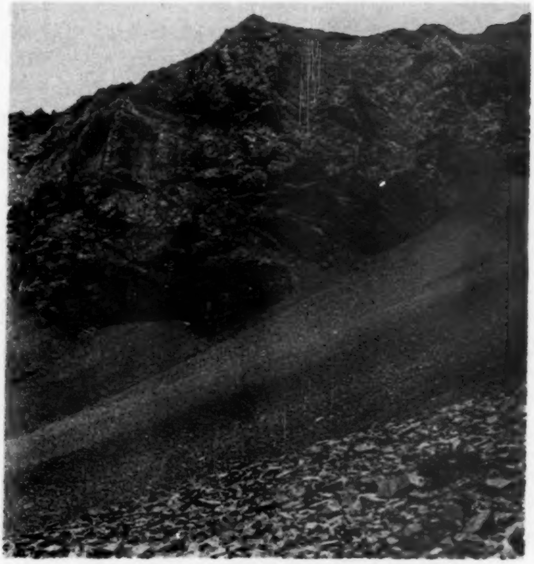


FIGURE 1. CONTORTED BEDS OF BASAL MEMBER OF BRAZER LIMESTONE
On upper reaches of Long Lost Creek where trail to Upper Cedar Creek starts to climb. Note thin banding and abundant fine talus.

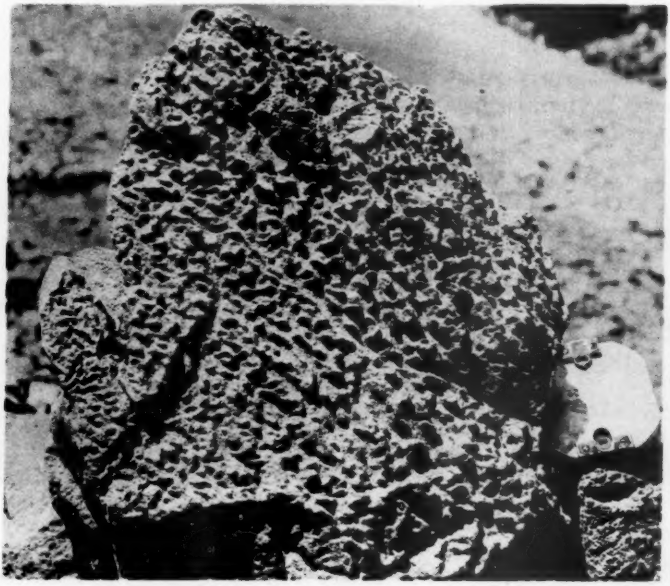


FIGURE 2. ETCHED BLOCK OF BRAZER LIMESTONE
From talus that floors an ephemeral lake southeast of the 11,504-foot peak near Swauger Lakes.

SPECIAL FEATURES OF THE BRAZER LIMESTONE wide near the southeast corner of the quadrangle and about 10 miles wide near the northwest corner. It is cut almost in two at Doublesprings Pass and north of the pass is called the Pahsimeroi Mountains.

The sinuous, serrate crest line of the range (Pl. 1, Profile e-e′) is within 2 or 3 miles of the southwestern border of the mountains. It culminates in Borah Peak, 12,655 feet, and the 30 principal peaks south of Doublesprings Pass average 11,731 feet in altitude. The Pahsimeroi Mountains, north of the pass, crowned by Dickey Peak, 11,140 feet, and 22 principal peaks average 10,750 feet in altitude.

The narrow, southwestern flank of the range is steep and locally precipitous. It rises in steps, some of the treads of which, especially in the Pahsimeroi Mountains, are gently inclined to the northeast. The numerous, short gorges that plunge from the range crest to the border of the alluvium have cut the stepped range front into a series of narrow masses elongated normal to the crest and resting against the main mass of the range like buttresses of a medieval fortress (Pl. 2, fig. 1). This feature of the topography is somewhat inadequately shown on the topographic map largely because of lack of space for proper delineation on a map of this scale. Profiles a-a′ and d-d′ (Pl. 1) show two of the larger steps or benches. The bench shown near the west end of profile a-a′ is accentuated by the fact that tributaries of the transverse gorges, incised into the range flank at short intervals, have here begun to cut into the ridge and lower the saddle at the northeast end of the bench. A little farther north, in Crane Basin, the same process has separated the steep outer front of the range from the mountain face below the crest line by forming a broad depression, the inner side of which presents a front similar to that of the range itself. Only the eastern side of Crane Basin is included in the Borah Peak quadrangle; the rest is in the Bayhorse quadrangle. The tendency for the transverse gorges to branch headward is evident in several other places along the range front, such as Upper Cedar Creek. All along the range erosion tends to produce a continuous inner front which in steepness and in the faceting of spur ends closely simulates the present range front.

The northeastern flank of the range is strikingly different. A line from range crest to valley border would be inclined less than 10° nearly everywhere and in some localities would be less than 5°. This flank is marked by long winding ridges that in the Pahsimeroi Mountains lie within a few hundred feet of an altitude of 10,000 feet and farther south are still higher (Pl. 1). The tops of these ridges, generalized on the map, are broader than those of the much shorter buttresses on the southwest flank of the range, and even more out of harmony with the steep-walled, glaciated valleys between them. Although the ridge crests slope gently toward the valley of the Pahsimeroi, much of the drop in altitude is accomplished in a zone 3–6 miles wide between the tips of the ridges and the valley border. Large portions of the ridge tops are much more nearly flat than might be inferred from inspection of the generalized contours on Plate 1. Figure 1 of Plate 8 shows a small part of one of these comparatively flat areas in the foreground. This view is taken southwest across Rock Springs Creek and shows the ridge south of that stream in profile. Although, as the photograph shows, parts of the valley of Rock Springs Creek are precipitous much of the ridge top south of it is as nearly flat as the area in the foreground of the picture.

The ridge crest of which this foreground is a part is similar in altitude to that on the sky line, a fact which is obscured in the picture because the camera was tilted.

In spite of the presence of these relatively flat ridge tops, and the gentle tilt of the mountain mass toward the valley of the Pahsimeroi, the closely spaced, steep valleys make the northeastern flank almost as rugged as the southwestern. Measurement on the map of the average slope of the ground by Rich's (1917, p. 105–109) method indicates that this slope is a little less than 16° on the northeast and a little less than 20° on the southwest side of the range. A larger-scaled and more precise map would probably result in increasing these figures. It would make the comparatively level parts of ridge tops more manifest than the present map does but, to an even greater extent, it would bring out the cliffed valley sides and the series of rock benches conspicuous in the headwater reaches of most of the streams that extend into the higher parts of the range.

The mountains are covered with a sparse evergreen forest from altitudes of about 10,000 feet down almost to the valley borders. On the lower slopes sage brush and, locally, mountain mahogany are plentiful. Grasses are sufficiently abundant to provide grazing for sheep and cattle throughout all but the highest parts of the mountains. The precipitation in the higher parts of the range is thought to be as much as 30 inches annually (Hoyt, 1935, p. 17, 23–25), which should be sufficient to give the principal mountain streams perennial flow. Nevertheless, during most of the year water flows at the surface only in certain stretches in all but a few of the streams in the mountains. Many of the mountain valleys have disproportionately small channels, and a few have no visible channels in their lower reaches. The east and west forks of the Pahsimeroi River are almost the only perennial streams.

The borders of the mountain ranges, marked by the sharp change in slope where the upper edges of the alluvial fans impinge against the bedrock hills, are, with minor exceptions, slightly above 7000 feet throughout the quadrangle. The slope of the valley floors, as determined by Rich's method, is nearly 2° on both sides of the Lost River Range. Few of the mountain streams maintain their channels far across the alluvium, and only the largest extend to the axes of the intermontane valleys.

THOUSAND SPRINGS VALLEY AND ADJACENT AREAS

Thousand Springs Valley is a roughly triangular area of about 60 square miles bordered on the east and west by moderately steep coalescing alluvial fans and with a nearly level marshy area extending southeastward across its center. The gravelly fans support a very sparse cover of sage brush, grasses, and other plants.

Most of the channels of the streams entering the valley lose their identity soon after reaching the upper borders of the fans. Few persist near the central part of the valley or connect with any through-flowing streamway. None of the streamways on the borders of the mountains now carry water at the surface during most of the year, in part because of irrigation diversions. Wherever distinct channels exist they are emphasized by lines of bushes and small trees (Pl. 2, fig. 2). Each group of channels unites into a single one shortly after leaving the mountain border, but the master channel is obliterated before it reaches Thousand Springs slough, (dark area in Pl. 2, fig. 2). The slough is fed by springs, mainly near its northern end, and is covered with wild hay. In the general vicinity of Whiskey Spring, water is sufficiently plentiful to stand at the surface in ponds and sluggish streams, an unusual feature in this part of Idaho.

The upper end of Thousand Springs Valley is separated from the country tributary to the Salmon River by a ridge somewhat over a mile wide and about 1000 feet high. North of this is a small part of Big Antelope Flat. Sheep Creek, along the south border of this flat, has water sufficiently near the surface to support considerable vegetation.

To the southward Thousand Springs Valley merges with Big Lost River Valley where the latter swings sharply from the northeast course it follows in its upper reaches to the southeast course it holds to the border of the Snake River Plain. The anastomosing channels of Lost River wander over a narrow flood plain incised in the irregular surface formed by the lower edges of fans descending from the surrounding mountains. This surface, especially south of the latitude of Chilly, is dotted with buttes of bedrock projecting through the alluvium. The flood plain of the river supports a tangled growth of bushes and trees, but during much of the year little or no water flows at the surface in certain stretches, especially near Chilly Post Office.

Thousand Springs Valley and the adjacent part of Big Lost River Valley support a population which at the time of this investigation probably numbered somewhat less than 200 people and decreased during the war. The residents lived on scattered ranches, mostly small, and raised wild hay and other forage crops.

PAHSIMEROI VALLEY

The upper half of Pahsimeroi Valley lies in the north-central part of the quadrangle. Most of it consists of well-developed gravel fans partially trenched by streamways from the mountains. More of the tributary stream channels connect with the main river than is the case on the other side of the Lost River Range. Nevertheless bluffs bordering both the tributaries and the Pahsimeroi itself tend to die out downstream, and the channels of most streams that emerge from the mountains are obliterated long before they reach the axis of the valley. North of latitude 44°20′ bluffs are intermittent and on the whole inconspicuous in the median part of the valley. South of this latitude the valley is furrowed by an elaborate set of bluffs ranging from a few inches up to 50 feet or more in height along both the Pahsimeroi River and minor subparallel streamways, some of which die out without reaching the river. Indeed, only Goldburg and Big creeks maintain well-defined channels in which water would probably flow at most seasons, if not interfered with by irrigation. Burnt and Doublespring creeks, and less distinctly a few of the others, have discernible streamways all the way to their confluence with the Pahsimeroi but only exceptionally carry water at the surface across the gravel-floored valley. The difficulty water finds in keeping close to the surface in the highly permeable materials that floor Pahsimeroi Valley is reflected in the comparative paucity of bushes and trees along most tributary streamways. Goldburg Creek is unique in that for much of its course it meanders through swampy meadows.

Within the Borah Peak quadrangle the valley of the Pahsimeroi contained, at the time of this study, about 20 inhabited ranches, which raised wild hay and other forage crops for sheep and cattle, including some dairy herds. The annual precipitation, both here and in Thousand Springs Valley on the other side of the Lost River Range, is probably a little less than 10 inches, judging by Weather Bureau records for near-by towns.

The valley of the Pahsimeroi River branches near its head, with the river in the wider, western branch, Goldburg Creek in the eastern, and the Donkey Hills between. The Donkey Hills, an almost completely isolated block, rise about 1500 feet above the Pahsimeroi near their western base and 1800 feet above the scarcely perceptible divide that separates Goldburg Creek from the swampy upper end of Summit Creek, a branch of Little Lost River.

LEHMI RANGE

The only part of the Lemhi Range within the Borah Peak quadrangle is the small area in the northeast corner of the quadrangle. Here the range is almost cut in two by the branches of Big Creek. The Lemhi Range is broadly similar in size, shape, and trend to the Lost River Range but is not so high nor so rugged. The highest peak studied rises 11,324 feet above sea level, and there are few, if any, higher peaks in the Lemhi Range. The average slope of the ground in the part of the range mapped in Plate 1 is about 16° as measured by Rich's method. The southwest slope of the range presents a series of fairly steep and straight fronts, broken into facets by the short transverse gorges. Within the quadrangle few such facets have slopes exceeding 22° as mapped, and the range front as a whole is not so steep as that on the corresponding side of the Lost River Range. High-level benches are conspicuous on both sides of the point where Big Creek enters Pahsimeroi Valley, and the alluvial fans are notably steep close to the mountains. The part of the range in the southeast corner of T. 13 N., R. 24 E., is carved into a series of benches at intervals from its base to its crest. These have facilitated lumbering for local uses. From here southeast to the quadrangle boundary the crest line maintains an altitude of close to 10,500 feet with a few rounded summits rising higher. The crest line of the mountains in the extreme northeast corner of the quadrangle, while higher, is likewise remarkably nearly level.

STRATIGRAPHY AND PETROLOGY

GENERAL FEATURES

The Borah Peak quadrangle contains a more complete stratigraphic record than any other part of south-central Idaho so far as now known. It includes rocks commonly regarded as pre-Cambrian and representatives of all pre-Permian Paleozoic periods except probably the Cambrian. No fossils of Cambrian age have been identified, and the two formations tentatively regarded as of that age in the Bayhorse region (Ross, 1938, p. 12–14) are missing here. Possibly, however, some of the dominantly quartzitic rocks older than the Kinnikinic quartzite may be of Cambrian age. The other principal contribution to the knowledge of the Paleozoic stratigraphy of this part of Idaho (Ross, 1934, p. 937–1000) that results from the study of this quadrangle is the recognition of the Three Forks limestone. If comparable beds exist farther west, they have yielded no fossils and therefore have not been recognized.

No Mesozoic stratified rocks, and few intrusive rocks that may be of that age, have been recognized in the quadrangle. Most of the different units of the Challis volcanics (late Oligocene or early Miocene) distinguished in the Bayhorse region (Ross, 1938, p. 49–68) are present, but this formation is by no means as well displayed here as it is farther west. Above the Challis volcanics is a unit here named the Donkey fanglomerate, not recognized in other parts of south-central Idaho, which may be of Pliocene age, and considerable amounts of Quaternary alluvium and glacial deposits. There are also a few exposures of basalt whose general appearance is so much less altered than that of basaltic rocks in the Challis volcanics that it may be Pleistocene.

STRATIGRAPHY OF THE BORAH PEAK QUADRANGLE

	Thickness (feet)
Quaternary	
Recent	
Alluvium	0–100+
Landslide material and hill wash	—
Travertine	—
Pleistocene	
Glacial deposits (probably also some alluvium and hill wash)	—
Unconformity	
Tertiary	
Pliocene(?)	
Donkey fanglomerate	0–1000+
Unconformity	
Late oligocene or early Miocene	
Challis volcanics	
Germer tuffaceous member	0–500+
Basalt and related flows	2500±
Latite-andesite member	1000±
Unconformity	
Carboniferous	
Pennsylvanian	
Wood River formation (mainly impure quartzite)	500+
Mississippian	
Brazer limestone	4000±
Milligen formation (mainly carbonaceous shale, some limestone)	1000±
Devonian	
Upper Devonian	
Three Forks limestone	20–350
Grand View dolomite	2000+
Jefferson dolomite	1000+
Silurian	
Laketown dolomite	6000+
Ordovician	
Upper Ordovician	
Saturday Mountain formation (mainly dark dolomite, some shale and quartzite)	500–700
Kinnikinic quartzite	3000±
Lower Ordovician	
Ramshorn (?) slate	2100+
Unconformity	
Pre-Cambrian	
Belt series	
Swauger quartzite	5000+
Lemhi quartzite	3000+

PRE-CAMBRIAN ROCKS—BELT SERIES

Subdivisions.—The oldest rocks in the quadrangle consist of a great thickness of dominantly quartzitic beds, without known fossils, that are regarded as belonging to the pre-Cambrian Belt series. These rocks are divided into two units, the lower of which is here named the Lemhi quartzite, after the Lemhi Range in which it is extensively exposed. This formation underlies most of the small part of Lemhi County that is included in the Borah Peak quadrangle. The formation that overlies it is here designated the Swauger quartzite after the Swauger Ranch whose grazing lands include much of the area in which it crops out within the quadrangle. While these old formations are definitely recognized only in the Lemhi Range, the possibility that the rocks of doubtful correlation east of the Elkhorn Ranch on the southwest flank of the Lost River Range include representatives of the Swauger quartzite cannot be eliminated.

Lemhi quartzite.—Within the Borah Peak quadrangle the Lemhi quartzite is exposed only in T. 14 N., R. 24 E., and the immediately adjacent parts of the Lemhi Range. Its best outcrops are along the branches of Big Creek. Similar impure quartzite crops out over large areas throughout the northern part of the Lemhi Range. When detailed geologic mapping of that range and of neighboring parts of the Salmon River Mountains is undertaken, it will probably be found that beds equivalent in age to this formation are widespread.

The Lemhi quartzite is composed principally of grayish-green impure quartzite, with subordinate argillaceous beds. The latter are darker than the quartzite, and some of them are purple and maroon. Here and there nearly pure white to pinkish quartzite forms lenses in the green quartzite. Such beds resemble some of those in the overlying Swauger quartzite. Typical green Lemhi quartzite is easily distinguishable from typical lavender Swauger quartzite, but the beds in both formations vary in color and composition so that in each there are beds lithologically indistinguishable from some of those in the other. The contact between the two units is gradational. East of Goldburg a lens of green quartzite is mapped on Plate 1 within the Swauger quartzite. Similar interbedding on a smaller scale is common along other parts of the contact.

Nearly all the beds of green quartzite are composed of about 90 per cent quartz, scattered plagioclase grains up to 10 per cent, and minor amounts of sericite, chlorite, apatite, and, locally, green biotite and dark tourmaline. In some beds biotite flakes are oriented at an angle of about 10° with the bedding planes. The green color characteristic of most of the Lemhi quartzite is modified by the impurities present so that some beds are nearly white, and others are dark gray. The beds in which pink or lavender tones obliterate the green are exceptional. The quartzite is moderately hard and compact. The original quartz and, to a less extent, the feldspar grains are roughly oval, and most of them have their long axes parallel, with lengths of from 0.05 to 0.5 mm. in different beds. These original grains are distinguishable in thin section by lines of dust around their borders. Figure 1 of Plate 11 shows the texture of a typical, rather coarse specimen in plane light. Secondary quartz has increased their size and their irregularity. This added quartz and perhaps also some of that of the original grains has been partially granulated, and the crushed material merges into the quartz of the matrix, or cement, composed of quartz and fine mica flakes. Most of the quartz of the original oval grains shows strain shadows under cross nicols. The shadows have random orientation, which may mean that the strains were induced before the grains were incorporated into the present rock. The comparatively rare feldspar grains are strikingly clear and fresh.

Argillaceous beds that are softer and more schistose than the quartzite are widely distributed but probably make up less than 10 per cent. They differ from the quartzite mainly because they contain a larger proportion of micaceous minerals, such as sericite and chlorite.

The Lemhi quartzite is jointed and shows incipient schistosity. The more impure, softer beds show this more than the quartzite, but none of the rock is thoroughly schistose. In most exposures traces of the original beds can be discerned, but in some outcrops bedding planes are obscure and might be confused with schistosity or joint planes. In general the schistosity strikes nearly parallel to the bedding but dips southwest. Most of the beds dip northeast.

The base of the Lemhi quartzite does not crop out within the quadrangle, and the beds roll so much that the exposed thickness cannot be estimated accurately. The difficulty in measurement is increased by the lack of satisfactory outcrops on most of the mountain slopes. Outcrops are plentiful at the heads of stream valleys and along parts of the stream gorges. Unless much undetected duplication by close folding or faulting exists, the formation must be several thousand feet thick.

Swauger quartzite.—The Swauger quartzite occupies most of the southern and eastern parts of the small portion of the Lemhi Range included in the Borah Peak quadrangle. It extends eastward beyond the limits of the quadrangle, but reconnaissance studies suggest that it is not so widespread in the northern part of the Lemhi Range as is the Lemhi quartzite. The formation underlies a considerable area in and near T. 11 N., R. 24 E., in the northern part of the Donkey Hills. Rocks of doubtful age exposed on the southwest flank of the Lost River Range between Elkhorn and Lone Cedar creeks include beds lithologically similar to the Swauger quartzite, but available data point to the early Paleozoic.

Most of the Swauger quartzite is composed of rather pure quartzite that varies from purple through deep brownish lavender and pinkish shades to almost pure white. Near the base and locally at higher horizons there are beds of green, relatively impure quartzite, and some of the lavender beds are locally greenish. Most of the quartzite is distinctly bedded, and some is cross-bedded. A few lenses of conglomerate and of rusty impure dolomite are included. Argillite is present at several horizons but is most conspicuous in the lower part of the formation. Argillaceous beds in the Lemhi Range are maroon, green, brown, and dark gray to nearly black. Both in color and in composition the argillite varies irregularly. Beds of different colors interfinger with each other and with quartzite beds. Individual lenses, also, vary in color and composition along the strike. Differences of this sort make it impractical, in most places, to distinguish the argillite beds on the map. A few exceptionally clear cut and well-exposed lenses are mapped (Pl. 1), but others that may well be equally large are not shown. In general, the Swauger quartzite is not so schistose as the Lemhi quartzite, probably because much of it is somewhat more competent.

The purple and lavender quartzite beds both in the Swauger quartzite and in the rocks of uncertain age near Sawmill Gulch are closely similar microscopically. Similarly colored quartzite beds near the base of the Ramshorn slate on Garden Creek and in the dominantly white Kinnikinic quartzite at Buster Lake, both in the Bayhorse quadrangle, have characteristics so similar that positive distinction by petrographic means seems impossible. The quartzite from all these places consists mainly of quartz grains that are distinctly water worn but in many beds are less perfectly rounded than those in the formations above and below the Swauger. The grains range in maximum diameter from 0.2 to 1.0 mm., in different beds, but most are less than 0.5 mm. Most of the quartz grains have been enlarged by addition of clear quartz in optical orientation with the original clastic grains. Exceptionally the quartz grains have been so crushed as to obscure their original form. Nearly all show strain shadows in random orientation. Many beds contain a little feldspar, and in some it constitutes more than 10 per cent of the rock (Pl. 11, fig. 2). Most of the feldspar is sodic plagioclase. Some is microcline. The feldspar grains are commonly smaller and less perfectly rounded than the quartz grains. Most of the rocks contain scattered grains of quartzite. The matrix consists of quartz grains rarely more than 0.02 mm. in diameter and abundant fine sericite flakes, generally not closely parallel to each other.

The color of the quartzite results from disseminated hematite dust. Some of this is coarse enough so that the crystal form is visible under high magnification. The hematite is nearly all outside of the original clastic grains, and the larger crystals tend to be along the boundary between these grains and the quartz that has been added to them. Thus the coloring matter obviously has crystallized since the rock was deposited and may well have been introduced at a late stage in the history of the rock. This suggestion is strengthened by the fact that the formation contains numerous lenses and discontinuous veins of coarse, white quartz with large foils of specular hematite. This may account for the somewhat erratic distribution of color in some places, notably near Sawmill Gulch. Hence, color may be a most unreliable guide in studying the stratigraphic relations of quartzites in the general region.

The argillaceous beds in the Swauger quartzite in the Lemhi Range consist mainly of somewhat irregular quartz grains, rarely more than 0.05 mm. in diameter, and fine, micaceous material. The quartz grains are similar in shape to those of the Lemhi quartzite and, like them, are probably detrital grains that have been somewhat crushed and recrystallized along their borders. Readjustments under pressure could be more readily effected in these rocks than in the nearly pure quartzites. Most of the argillaceous rocks contain plagioclase grains. Some of these resemble cleavage fragments, but others are well rounded and obviously of detrital origin. Micaceous minerals, which include sericite and chlorite, are plentiful, and the darker rocks contain numerous graphitic flakes. There are rare grains of dark tourmaline, possibly detrital, and in some beds a little carbonate.

Like the Lemhi quartzite below it, the Swauger quartzite has not been satisfactorily measured. The top and bottom are not present in any one exposure within the quadrangle, and the basal beds grade into the green quartzite below. In the vicinity of Flatiron Mountain the exposed thickness appears to be at least a mile. Farther south the beds roll so irregularly as to hinder measurement, but the total thickness present is probably as great.

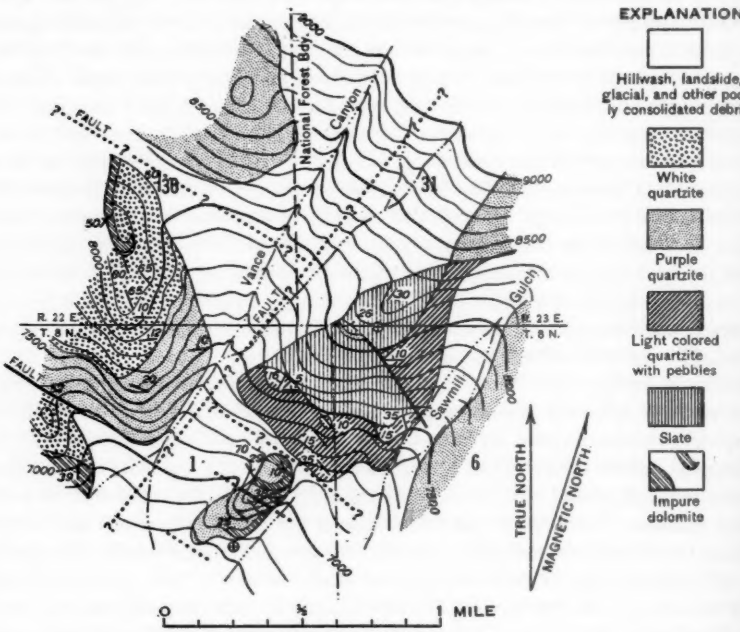
Age of the Lemhi and Swauger quartzites.—As the Lemhi and Swauger beds appear to be unfossiliferous their age can be judged only on the basis of their stratigraphic relations. The two formations grade into each other so intimately that both must belong to essentially the same period. They are part of the great mass of broadly similar rocks that Umpleby (1913a, p. 31–32, Pl. 1) mapped as pre-Cambrian. This assignment, which is still regarded as the most probable one, requires that the beds be regarded as part of the Belt series. Umpleby (1913a) thought than an unconformity exists between the rocks he assigned to the pre-Cambrian and those he regarded as of Paleozoic age. This is confirmed by reconnaissance work by the present writer in parts of the Lemhi Range north and east of the Borah Peak quadrangle. Near Rocky Creek, in this area, the Kinnikinic quartzite rests in angular unconformity on old rocks which in some localities are thought to belong to the Lemhi and in others to the Swauger quartzite. Within the Borah Peak quadrangle the relations of the old rocks to the Kinnikinic are everywhere obscure.

Kirkham (1927, p. 14–18, Pl. 4) in a reconnaissance of a wide area which includes part of the Borah Peak quadrangle grouped as Cambrian(?) part of the rocks that Umpleby regarded as pre-Cambrian and the quartzite here called Kinnikinic. Such a grouping reflects the fact that the Kinnikinic and Swauger quartzites cannot everywhere be distinguished without detailed mapping because the color difference alone is not reliable. There are nearly white beds in the Swauger quartzite and lavender beds in the Kinnikinic quartzite. Support for the suggestion that the Swauger may be of Cambrian age is given by the fact that Mansfield, who visited the region in 1936, regards the Swauger in T. 12 N., R. 25 E., and similarly colored beds in the Ramshorn slate of the Bayhorse quadrangle (Ross, 1938, p. 15, footnote) as lithologically like the Brigham quartzite (Cambrian) of southeastern Idaho (Mansfield, 1927, p. 52–53). This is offset by the fact that the color appears to be without significance as to age.

In northwestern Lemhi County some of the beds regarded as pre-Cambrian have been divided into the Yellowjacket formation and overlying Hoodoo quartzite (Ross, 1934, p. 15–20). The Yellowjacket bears a suggestive resemblance to the Lemhi quartzite, and the Hoodoo is similar to the purer quartzite of the Swauger except that it is white instead of lavender, a difference that may not be diagnostic.

Old rocks near Sawmill Gulch (*Age uncertain*).—The rocks between Elkhorn and Lone Cedar creeks and topographically below the Kinnikinic quartzite near the crest of the Lost River Range present some of the most puzzling stratigraphic problems in the quadrangle. The different lithologic components are in places thin and intricately interbedded. Faults and contorted beds are common. Satisfactory outcrops are rare, even on the ridges, and detritus of different kinds completely covers the bedrock in places. Figure 2 shows the part of the area that contains the most abundant exposures in greater detail than can be represented on Plate 1. Even here the numerous areas covered by unconsolidated material hinder interpretation of the relations between the bedrock units.

The rock on slopes immediately below the definitely recognized Kinnikinic quartzite and on the large ridge that separates Lone Cedar Creek and Sawmill Gulch con-



(Contour interval 100 feet)
(Datum is assumed mean sea level)

FIGURE 2.—*Geologic and topographic sketch map of an area near Sawmill Gulch*

sists mainly of dark-lavender quartzite (Pl. 11, fig. 3), most of which is microscopically indistinguishable from the lavender Swauger quartzite near the Swauger Ranch. Conglomerate is somewhat more plentiful than it is in the latter locality, and some of the quartzite contains scattered pebbles 30 mm. and more in diameter. The scattered outcrops on the slopes close to Elkhorn Creek contain quartzite of several different kinds. Much of this quartzite is almost as white as typical Kinnikinic quartzite, but some is lavender and purple. Some beds of impure dolomite and of slate are much like those mapped separately near Sawmill Gulch. Most of the different units in the latter area that have been distinguished on Figure 2 might also be recognized on the ridges close to Elkhorn Creek. Outcrops are so scattered, however, that mapping in detail would probably be profitless.

The rock units distinguished on Figure 2 include white, locally very pale-lavender quartzite (600 feet), purple or dark-lavender quartzite (500 feet), slate (500 feet), light-colored quartzite with scattered pebbles (500 feet), and impure dolomite. The last is locally intercalated in the quartzite. On Plate 1 the white and light-colored quartzites are grouped together. The faulted block of quartzite in the western part of section 1, T. 8 N., R. 22 E., may contain as much as 200 feet of beds. The others are thinner. The dolomite in the undifferentiated rocks near Elkhorn Creek is probably nowhere much over 100 feet thick. All estimates of thickness here given are only approximate as the exposures are too scattered and the rocks too much deformed for accurate measurement. The stratigraphic relations between the different units are in part indeterminate because of numerous faults, much covering detritus, interfingering relationships, and possible lateral variations in such distinguishing features as color.

In the hand specimen the white quartzite of the area mapped in Figure 2 and similar rocks elsewhere in this vicinity resemble Kinnikinic quartzite, but under the microscope much of the quartzite is a mosaic (Pl. 11, fig. 4) instead of the aggregate of rounded grains (Pl. 11, fig. 5) from a typical specimen of Kinnikinic quartzite. However, definitely recognizable Kinnikinic quartzite elsewhere locally has textures similar to that shown in Figure 4 of Plate 11, and beds of impure, rusty quartzite among the white rocks in the vicinity of Sawmill Gulch contain fully as well-rounded grains as those shown in Figure 5 of Plate 11. Textures like that shown in Figure 4 of Plate 11 result largely from greater irregularity in the form of the original detrital grains. The irregular shape permits such grains to pack into a compact mosaic, and sharp projections are granulated with relative ease. The granulated and recrystallized peripheral material tends to obscure the original form of the grains. Smoothly rounded grains have no edges to break off, and their original forms tend to remain visible under the microscope even though the grains may be coated with later quartz. Some of the white quartzite from the area near Sawmill Gulch contains a little rutile, zircon, and tourmaline. The zircon and probably part of the tourmaline are of detrital origin.

The lavender and purple quartzite beds of this area are, for the most part, megascopically and microscopically similar in their appearance to the Swauger quartzite near the Swauger Ranch except that no feldspar has been recognized in them. Some are coarser and more irregularly grained (Pl. 11, fig. 3), and conglomerate beds and scattered pebbles in the quartzite are more common here than in the Lemhi Range. Hematite colors the late quartz that encases the well-worn quartz grains. Some of the quartzite is cut by quartz veins with specular hematite, but these are less plentiful than in the Lemhi Range. Tourmaline is more plentiful in the area near Sawmill Gulch than in the Swauger quartzite of its type locality. There seems to be no diagnostic difference between the purplish beds in the different exposures in the area mapped in Figure 2 in spite of the differences in the details of stratigraphic relations.

The slate near Sawmill Gulch is more like the Ramshorn slate of the northern part of the Bayhorse quadrangle (Ross, 1938, p. 14–16) than any of the argillaceous members of the Swauger quartzite in the Lemhi Range. It is a rather dark-green and and purple banded rock with numerous sandy layers and some interbedded purple quartzite. Some of the sandy layers are ripple-marked. There is well-developed slaty cleavage. The beds are probably much contorted, but exposures are inadequate for interpretation of structural details. Quartz, sericite, biotite, chlorite, hematite, pyrite, zircon, and tourmaline are recognized. A few narrow lenses of similar slate are interbedded with nearly white quartzite and with impure dolomite in sec. 36, T. 9 N., R. 22 E.

The light-colored quartzite with scattered pebbles is nearly as white as the white quartzite but is speckled with rust spots, presumably oxidized pyrite, and is comparatively coarse-grained. Well-worn grains are exceptional, and the cement is granulated quartz. There is some mica and a little tourmaline and rutile. Most of the pebbles are quartzite, but some of the smaller ones are slate.

The dolomite is dark gray and indistinctly banded. It is composed of a crystalline mosaic of dolomite grains that range from 0.04 to 0.20 mm. It thus has no diagnostic features that would distinguish it from the dark dolomitic beds in several of the Paleozoic formations in the region.

A large part of the rocks above described definitely underlie the Kinnikinic, and, with the possible exception of the dolomite, none resemble units stratigraphically above that formation. Some of the light-colored quartzite is so similar lithologically to the Kinnikinic quartzite as to suggest that it may represent downfaulted blocks of the latter. The close association and local interbedding of white, and faintly colored quartzite with rocks distinctly different from those in the recognized Kinnikinic of the Borah Peak quadrangle casts doubt on such an interpretation. However, in the Dome mining district (Ross, 1933, p. 3–5) a similar aggregate of light and purplish quartzite, and argillaceous and dolomitic rocks underlies an Upper Ordovician dolomite doubtless broadly equivalent to the Saturday Mountain formation. The suggestion has been made (Ross, 1934, p. 949–950) that this aggregate may be approximately equivalent to the Kinnikinic quartzite. An alternate suggestion would be that only the upper white quartzite of the Dome district represents the Kinnikinic and that the units below are older, perhaps roughly equivalent to the Ramshorn slate. Marked lateral variations exist in the Ordovician rocks in this part of Idaho. For example the rocks of this age in the Hailey quadrangle have little resemblance to those in the Bayhorse quadrangle immediately to the north (Ross, 1934, p. 942–956). Thus lithologic changes within fairly short distances, such as those postulated above, are to be expected.

Near Sawmill Gulch the argillaceous rocks are strikingly like some of those in the Ramshorn slate of the Bayhorse quadrangle, and the purple and lavender quartzites, especially the conglomeratic beds, are as similar to beds near the base of the Ramshorn near Garden Creek in the Bayhorse quadrangle as they are to the Swauger quartzite or to any other rocks in the region. Hence these rocks are thought to be equivalent to the Ramshorn slate, although some blocks among them may belong to the Kinnikinic quartzite. When these rocks were first encountered in the field the conspicuous purple and lavender quartzite beds suggested correlation with the Swauger. This possibility cannot be entirely eliminated on present evidence, but on the whole assignment of the assemblage to the lower Paleozoic seems best to fit the known facts.

PALEOZOIC ROCKS

Kinnikinic quartzite.—Outcrops of Kinnikinic quartzite occur in the ridges in the southern part of T. 13 N., R. 22 E., and in a band roughly a mile wide which crosses the Donkey Hills at their highest part and extends northeast into a spur of the Lemhi Range. A more irregular and complex mass of the formation crops out along the west side of the upper valley of the West Fork of the Pahsimeroi River and extends southwest across the crest of the Lost River Range to the border of Thousand Springs Valley.

In all three localities most of the formation consists of rather thick-bedded, nearly white, pure quartzite similar to most of that which makes up the Kinnikinic quartzite in its type locality (Ross, 1938, p. 17, 18). Typical material from this formation consists almost exclusively of quartz, mainly in detrital grains which range up to about half a millimeter in diameter. In some of the rocks the grains are well rounded (Pl. 11, fig. 5), but in others they are irregular (Pl. 11, fig. 4). Quartz added in optical continuity with the original grains is locally present but is far less prevalent than in the Swauger quartzite. Some of the rocks show closely spaced lines of fluid inclusions in the detrital grains of the sort that Harker (1932, p. 240–241) attributes to the effects of strain in an early stage of metamorphism. In many the quartz grains are free from inclusions. Almost the only constituents other than quartz in the typical quartzite of this formation are the sericite flakes in a few of the quartz grains, and rare grains of brown tourmaline.

In the southern part of T. 13 N., R. 22 E., the lower part of the formation is concealed by alluvium. The main mass of the formation is composed of nearly white, massive quartzite. Locally joints parallel the bedding but in the less-jointed exposures the bedding planes are marked only by faint lines of dust. Some of the quartzite is stained by iron oxides. Fucoid casts are sparsely distributed. At the top of the formation joints along the bedding are more closely spaced, and locally the quartzite is interbedded with the dolomite of the overlying formation. Some of the dolomite has been partly silicified. As the quartzite ridges are separated by valleys floored with alluvium satisfactory measurements of the total thickness cannot be made. In the largest of the ridges alone fully 2000 feet of beds are present.

In the Donkey Hills the main mass of the Kinnikinic quartzite is similar to that above described. The upper contact is sharper than it is in T. 13 N., R. 22 E., but appears to be conformable. Near Goldburg Creek the base is concealed by a fault which dies out to the southwest so that the entire formation is probably exposed close to the crest of the hills. The thickness here is about 3000 feet. In a few places near the base of the white quartzite there are narrow beds of rusty siliceous dolomite and of conglomerate.

In the area near the head of the West Fork of the Pahsimeroi the intricate deformation locally introduces some uncertainty into stratigraphic correlation, and the numerous cliffs and widespread talus slopes add to the difficulties of mapping. Most of the formation consists of white quartzite identical with that in the other localities. Some of it has distinct lavender tints, and there are a few beds as deeply colored as the underlying lavender quartzite. Some of the quartzite, notably near the Jayrock prospect, is rusty and in part dolomitic. In places near the crest of the range, and also on the lower slopes on the west side of the West Fork of the Pahsimeroi, dark dolomitic and argillaceous rocks are conspicuous. A narrow band of dark-bluish dolomite (with some argillite that crops out in the cirque at the head of Elkhorn

Creek and crosses the range crest to the northeast), is locally much contorted and seems to be interbedded with the white quartzite. Part of the argillite and dolomite, locally schistose, that crops out in the vicinity of Pass Lake and extends in a narrow band to the northwest is probably also to be correlated with the Kinnikinic. However, these rocks are within a zone of marked disturbance along a thrust fault and unquestionably include fragments of younger formations that have been caught in the fault zone. As it has proved impractical to separate these younger rocks on Plate 1, the whole contorted mass has been mapped as a fault complex. Probably much of this complex is made up of Devonian rocks. Vestiges of fossils are visible in outcrops scattered through it, and near Leatherman Pass fossils of probable Jefferson and Three Forks age were obtained from it.

In its type locality in the Bayhorse region the Kinnikinic quartzite was thought to be of Lower or Middle Ordovician age (Ross, 1938, p. 18) on the basis of its relations to fossiliferous formations above and below. No diagnostic fossils were found in the Kinnikinic itself. Recently further evidence on the age of this formation has been obtained in the vicinity of Gilmore, on the east flank of the Lemhi Range. Vernon Scheid made detailed studies in the Gilmore area in 1940 and 1941 in the course of which he and Josiah Bridge obtained well-preserved fossils from the Kinnikinic quartzite. These have been examined by G. Arthur Cooper, U. S. National Museum, who reports orally that they appear to be "of early Upper Ordovician age, approximately that of the Fernvale formation of the Mississippi Valley". Cooper's determination appears to fix the age of the formation more closely than was previously possible. The correlation between the quartzites assigned to the Kinnikinic in the Gilmore, Borah Peak, and Bayhorse areas seems certain, even though they cannot be traced from one area to the other because of the cover of younger rocks.

Saturday Mountain formation.—The distribution of the Saturday Mountain formation in the Borah Peak quadrangle is similar to that of the Kinnikinic quartzite which immediately underlies it. One band of outcrops lies on the lower slopes on the northeast side of Mahogany Hill in and near the southwest part of T. 13 N., R. 22 E. Another crosses the Donkey Hills near the southwest corner of T. 11 N., R. 25 E. Irregular, much-disturbed masses crop out in the area between Borah Peak and the West Fork of the Pahsimeroi River.

The Saturday Mountain formation has broadly uniform characteristics in nearly all exposures in the Borah Peak quadrangle. Most of it is a dull, dark-bluish gray, almost black, somewhat impure dolomite. Analysis NC 71 in Table 1 shows the composition of typical material, and Figure 1 of Plate 12 shows the texture of the analyzed rock. Bedding planes are rarely distinct and in many exposures cannot be seen. The rock breaks irregularly into sharply angular pieces. Some beds contain small nodules and bands of light-colored chert in irregular masses, and some have been partly silicified. Locally the dolomite is comparatively light-colored, possibly as a result of weathering. In places the dark dolomite is irregularly mottled with light patches. On some ridges near the upper reaches of the West Fork of the Pahsimeroi a narrow zone of sheared, somewhat dolomitic shale separates the massive dolomite from the underlying Kinnikinic quartzite, and in other localities the dolomite and quartzite are interbedded along the contact.

The thickness of the formation was directly measured only in the area northeast of Mahogany Hill. In this locality fully 700 feet of dolomite is exposed. Below the measured beds, scattered outcrops of greatly disturbed beds of dolomite and more or less dolomitic quartzite mark the transition between the dolomite of the Saturday Mountain formation and the Kinnikinic quartzite. The transition zone appears to be about 200 feet thick but cannot be measured accurately. In other localities the transition zone is less conspicuous, and the dolomite typical of the Saturday Mountain formation appears to have an average thickness of roughly 500 to 600 feet.

There is an appreciable difference in lithologic characteristics between the rocks of the Saturday Mountain formation in the Borah Peak quadrangle and those of corresponding age in the Bayhorse region (Ross, 1938, p. 18–22). In the western part of the Bayhorse quadrangle, the type locality, the formation is thick and contains much carbonaceous shale. Farther east in that quadrangle the formation is much thinner and consists mainly of dolomite similar to the lighter-colored beds in the Borah Peak quadrangle. Still farther east, in the area here described, the thickness has again increased slightly, but beds other than dolomite are subordinate and appear mainly near the base. The shaly beds at the base along the West Fork of the Pahsimeroi are much like the more dolomitic of the shaly beds near Saturday Mountain in the Bayhorse region.

The stratigraphic position of these beds in the Borah Peak quadrangle is identical with that of the Saturday Mountain formation in the Bayhorse region (Ross, 1938, p. 18–22) in spite of the differences in lithologic detail commented upon above. The correlation is confirmed by the fact that study by Edwin Kirk of six fossil collections from widely separated localities in the Borah Peak quadrangle show that these beds, like the corresponding ones farther west, are of Upper Ordovician age. The determinations made by Kirk are as follows:

Coll. 3—From upper reaches of first large gulch south of the Rock Creek that is tributary to the Pahsimeroi, 200–300 feet southwest of the stream channel. Collected September 5, 1935 by J. S. Williams: *Streptelasma* sp., *Dalmanella* sp., *Rhynchotrema* sp.

Coll. 4—From about half a mile west, up the ridge, from the collection listed above. Collected September 5, 1935 by J. S. Williams: *Streptelasma cf. trilobatum* Whiteaves, *Rhynchotrema* sp.

N.C. 23. From small isolated fault block of Saturday Mountain strata on the ridge that forms the north wall of Elkhorn Canyon. Collected August 2, 1936 by N. E. Chute: *Hebertella* sp., *Dinorthis* sp., *Dalmanella* sp., *Rhynchotrema* sp.

B.P. 560. From head of Cedar Creek. Collected August 31, 1936 by C. P. Ross: *Streptelasma cf. trilobatum* Whiteaves.

C.L. 87. On Donkey Hills above Garrett Ranch. Collected September 1935 by Charles Lee: *Streptelasma* sp., *Dalmanella* sp., *Hebertella* sp.

B.P. 106. From crest of Donkey Hills. Collected September 1935 by C. P. Ross. *Streptelasma* sp., fragmentary.

Laketown dolomite.—The Laketown dolomite crops out on the slopes east of both Meadow Peak and Mahogany Hill in the northwestern part of the Borah Peak quadrangle. Exposures of it also cross the middle part of Donkey Hills. Irregular masses of the formation crop out in several places in the area bounded by Mahogany Creek, the West Fork of the Pahsimeroi, and Thousand Springs Valley.

Here, as in the Bayhorse region (Ross, 1938, p. 22–25), the Laketown dolomite is composed mainly of light bluish-gray dolomite. In many places the dolomite has a pale-reddish tint because of disseminated iron oxide. In most exposures it can be readily distinguished from the underlying dolomite of the Saturday Mountain formation because it is much lighter-colored and somewhat more distinctly bedded. In some localities, however, much of the formation is as dark, and in places even darker, than the lighter parts of the Saturday Mountain formation. In such localities isolated exposures of one formation may introduce uncertainty. Commonly, however, the relations between a doubtful outcrop and others which exhibit characteristic features make correlation easy. Chert is locally present, but it is nowhere abundant. Some of the beds are sandy, and there are local quartzitic lenses too small to be distinguished on Plate 1.

Chemically, so far as can be judged from the data in Table 1 there is no essential difference between typical Laketown dolomite and the characteristic rocks of the underlying and overlying formations. The Laketown dolomite is a little coarser and more uneven in texture than most of the dolomite of the Saturday Mountain formation. Some grains are almost 0.1 mm. in diameter, twice as large as the usual grains in the Saturday Mountain strata. The quartzitic beds in the Laketown differ markedly from those in the older formations (Pl. 12, figs. 2, 3). The quartzite in the Laketown is a fine, crystalline mosaic whose appearance both in the field and under the microscope suggests that it is, in part, a replacement of dolomite.

The thickness of the Laketown dolomite has been directly measured only in the area northeast of Mahogany Hill where it is over 600 feet thick. In most other exposures the thickness is about the same. In the general vicinity of Borah Peak the thickness may be a little greater, but the beds here are too deformed for accurate measurement.

Both stratigraphic position and lithologic characteristics establish conclusively the correlation between the rocks here grouped in the Laketown dolomite and those so designated in the Bayhorse region (Ross, 1938, p. 23–25). Fossil collections, listed below, from 12 localities in the Borah Peak quadrangle, according to Edwin Kirk, establish the middle Silurian age of the formation. The fauna in these collections is very similar to that found by Kirk in collections from Laketown beds in the Borah Peak quadrangle.

C.L. 26. From the spur northwest of the Rock Creek that drains into the Pahsimeroi. Collected August 10, 1935, by Charles Lee: *Favosites* sp., *Diphyphyllum* sp.

B.P. 65. From cliff at the main lake in the second creek south of the Rock Creek that drains into the Pahsimeroi. Collected August 11, 1935, by C. P. Ross: *Heliolites* sp., *Amplexus* sp., *Cyathophyllum* sp., *Diphyphyllum* sp.

C.L. 28. From the first gulch south of the Rock Creek that drains into the Pahsimeroi. Collected August 11, 1935, by Charles Lee: *Heliolites* sp., *Diphyphyllum* sp.

C.L. 29. From the spur south of the head of the Rock Creek that drains into the Pahsimeroi. Collected August 11, 1935, by Charles Lee: *Halysites catenulatus* Linné, *Amplexus* sp., *Heliolites* sp.

Coll. 5. From ridge south of the head of the first large gulch south of the Rock Creek that drains into the Pahsimeroi. Collected September 5, 1935, by J. S. Williams and C. P. Ross: *Halysites catenulatus* Linné, *Amplexus* sp., *Heliolites* sp., *Cladopora* sp., *Diphyphyllum* sp.

C.L. 69. From trail at base of Borah Peak, collected September 8, 1935, by Charles Lee: *Diphyphyllum* sp., *Cyathophyllum* sp., *Cladopora* sp.

C.L. 70. From trail up Borah Peak. Collected September 8, 1935, by Charles Lee: *Halysites catenulatus* Linné, *Coenites* sp., *Spirifer* sp., *Atrypa reticularis* Linné.

C.L. 71. From trail up Borah Peak at barometric altitude 12,400 feet. Collected September 8, 1935, by Charles Lee: *Cyathophyllum* sp., *Heliolites* sp., *Atrypa reticularis* Linné.

C.L. 72. From trail near top of Borah Peak at barometric altitude 12,500 feet. Collected September 8, 1935, by Charles Lee: *Heliolites* sp., *Diphyphyllum* sp., *Amplexus* sp.

C.L. 85 and C.L. 86. Near summit of the Donkey Hills. Collected August 16, 1935, by Charles Lee and C. P. Ross: *Halysites catenulatus* Linné.

N. C. 59. From the northern front of the first large gulch south of the Rock Creek that drains into the Pahsimeroi. Collected August 31, 1936, by N. E. Chute: *Aulopora* sp., *Heliolites* sp., *Coenites* sp., *Favosites* sp., *Halysites catenulatus* Linné, *Atrypa reticularis* Linné.

Jefferson dolomite.—The Jefferson dolomite crops out on and near Meadow Peak and Mahogany Hill and in the canyon of Grouse Creek in the northwestern part of the Borah Peak quadrangle. Exposures of it cross the Donkey Hills somewhat south of their center. The formation crops out extensively in the general vicinity of Borah Peak. It also forms a broad band on the lower slopes of the Lost River Range between Upper Cedar and Lone Cedar creeks.

Here, as in the Bayhorse region (Ross, 1938, p. 25–27), the Jefferson dolomite is composed mainly of dark bluish-gray dolomite which, in many exposures, contains an abundance of a characteristic digitate form of *Favosites*. These fossils and the distinctive color of the rock commonly make the formation easily identifiable, even in isolated outcrops. The color of the typical dolomite is even more nearly black and is also brighter than that of the principal beds in the Saturday Mountain formation. The dolomite is somewhat irregularly textured. In much of it the grains tend to show crystal form, which may account for the bright or "live" appearance of the rock (Pl. 12, fig. 4). On the whole the rock is somewhat coarser-grained than the dolomite in underlying formations. Some of the beds, especially near the base of the formation, are lithologically indistinguishable from the light-gray dolomite characteristic of the underlying Laketown, except that some are somewhat coarser-grained (Pl. 12, fig. 5). These, however, make up so small a part of the formation that they rarely introduce any difficulty in correlation. The two analyses of dolomite from the Jefferson (Table 1) show that it differs little in composition from the dolomite in underlying formations. The lighter-colored sample (Pl. 12, fig. 5) proved to be a little more siliceous and less carbonaceous than the dark one (Pl. 12, fig. 4). Yellowish-buff, massive beds of calcareous sandstone or quartzite are conspicuous just above the base of the formation in some localities, and similar rock forms lenses at higher horizons also. The component grains are principally quartz but include some microcline. They are water worn but not very smooth, and many show check marks as though they were weathered before being incorporated in the rock. A few have strain shadows. The diameters range up to half a millimeter. The cement is calcareous and in some beds is abundant (Pl. 13, fig. 1).

Some of the beds in the Jefferson dolomite are so similar to some of those in the overlying Grand View dolomite as to introduce uncertainties in the identification of isolated exposures. Where it is possible to view the two formations as units, the differences between them are obvious. The Jefferson is composed dominantly of thick-bedded, nearly black, fresh-looking dolomite, while most of the Grand View is lighter-colored, thinner-bedded and tends to be somewhat rusty in weathered outcrops.

In detail, the Jefferson dolomite varies from place to place. In exposures in the northern half of the quadrangle characteristic bluish-gray, nearly black dolomite constitutes at least 80 per cent of the whole, and most of the other beds are composed of dolomite that is only a little lighter-colored, rustier, or more sandy. The aggregate thickness of the formation in this part of the quadrangle averages about 600 feet. In the southern half of the quadrangle the formation is more intricately deformed, and satisfactory sections of the entire unit were not found. However, the thickness is much greater. The lower part of the formation here contains thick beds of calcareous quartzite and of very light-gray dolomite that are either absent or scantily represented in all exposures in the northern half of the quadrangle. These rocks are interbedded with typical dark-bluish gray dolomite and appear to be inseparable from the rest of the Jefferson dolomite. They do, nevertheless, record different conditions of deposition and may indicate that, in the southern half of the quadrangle, the formation began to be deposited slightly earlier and under the influence of more powerful currents than it did farther north.

The two sections following are representative of the formation in the southern half of the quadrangle. Both show a thickness of over 800 feet, and the total thickness must be several hundred feet greater. Although the two sections are exposed in localities little more than a mile apart, they differ in a number of details.

Section of Jefferson Dolomite in the Large Cirque North of Borah Peak

	Thickness (feet)
Mainly dark dolomite, some lighter, rusty beds and a few sandy lenses. Not well exposed on line of traverse	—
Nearly black, indistinctly bedded dolomite	200±
Dark, moderately well-bedded dolomite	75
Dolomite in alternately light and dark beds	60
Nearly black dolomite with lighter beds at intervals	93
Light dolomite	60
Yellowish buff calcareous quartzite, distinctly bedded, some rusty chert in bands and nodules	110
Nearly black dolomite	2
Yellowish-buff calcareous quartzite	11
Light-gray dolomite	14
Nearly black, banded dolomite	148
Yellowish buff calcareous quartzite	60
Nearly black dolomite	43
Total thickness of measured part of section	876

Section of Jefferson Dolomite on the Ridge on Which the Southwest Corner of Sec. 36, T. 10 N., R. 22 E. is Situated

	Thickness (feet)
Nearly black dolomite at west end of ridge	—
Alternate beds of moderately light and dark dolomite. Some beds very light gray. A few thin quartzite layers	200
Moderately dark dolomite	42
Thin-bedded, dark dolomite	57
Alternate beds of dark- and light-colored dolomite	12
Nearly black dolomite	9
Moderately dark dolomite	34
Yellowish-buff calcareous quartzite	49
Alternate beds of light and moderately dark dolomite. The light-colored beds predominate	239
Yellowish-buff calcareous quartzite	145
Nearly black dolomite	13
Total thickness of measured part of section	800

The correlation between the beds here assigned to the Jefferson dolomite and those so designated in the Bayhorse quadrangle (Ross, 1938, p. 25–27) is clear. The fossil collections have been studied by Edwin Kirk with the results listed below. He comments:

"The lots here identified as Jefferson are probably of that age. It is a question, however, whether the Jefferson should be classified as high Middle Devonian or low Upper Devonian. In the East the Upper-Middle Devonian boundary is tentatively drawn and fluctuates to a considerable degree. So far as the Jefferson is concerned, with its meager fauna, the question is largely academic. Inasmuch as the Jefferson has hitherto been classed as Middle Devonian, it should remain there."

Since Kirk made the statement quoted above new studies by Sloss and Laird (1946) lead them to regard the Jefferson dolomite in Montana as of Upper Devonian age. Their decision is here accepted for the equivalent beds in central Idaho.

B.P. 10. From Elkhorn Creek. Collected July 22, 1935, by C. P. Ross: *Cladopora* sp.

B.P. 44. From ridge on the southeast side of Mahogany Creek. Collected August 5, 1935, by C. P. Ross: *Diphyphyllum* sp., *Aulopora* sp., *Cyathophyllum* sp.

C.L. 21. From Mahogany Creek. Collected August 21, 1935, by Charles Lee: *Pachypora* sp., *Alveolites* sp.

B.P. 109. From the west flank of the Donkey Hills collected August 30, 1935, by C. P. Ross: *Cladopora* sp., *Atrypa* sp.

Coll. 1. From near the head of Mahogany Creek, on the west side of the syncline. Collected September 2, 1935, by J. S. Williams and C. P. Ross: *Diphyphyllum* sp., *Prismatophyllum* sp., *Aulopora* sp.

B.P. 124a. From about 110 feet above base of measured section at head of the Rock Creek on the west side of the Lost River Range. Collected September 3, 1935, by C. P. Ross: *Favosites* (digitate form), *Bellerophon(?)* sp. and other, indeterminable gastropods.

B.P. 119. About 1518 feet, vertically, above base of measured section at head of the Rock Creek on the west side of the Lost River Range. Collected September 3, 1935, by C. P. Ross: *Bellerophon* sp.

Coll. 1. From near the base of the Jefferson in the upper reaches of the Rock Creek that is tributary to the Pahsimeroi. Collected September 5, 1935, by J. S. Williams and C. P. Ross: *Stromatopora* sp., *Favosites* (digitate form), *Aulopora* sp.

Coll. 2. From about 120 feet stratigraphically above the location of Coll. 1, on the upper reaches of the Rock Creek that is tributary to the Pahsimeroi. Collected September 5, 1935, by J. S. Williams and C. P. Ross: *Favosites* (digitate form), indeterminable gastropods.

B.P. From a little more than a mile southwest of Borah Peak. Collected July 30, 1936, by C. P. Ross and N. E. Chute: *Pachypora* sp., *Pachyphyllum* sp., *Atrypa* sp.

B.P. 528. From a gulch south of Meadow Creek. Collected July 14, 1936, by C. P. Ross: Fossils not definitely determinable but probably Devonian.

N.C. 20. From Jefferson dolomite in the core of the anticline on Grouse Creek above the mouth of Mill Creek. Collected June 26, 1936, by N. E. Chute: *Cladopora* sp., *Diphyphyllum* sp., *Atrypa* sp.

B.P. 78. From the dolomite in the disturbed mass of overthrust material south of Leatherman Pass collected August 4, 1935, by C. P. Ross and Charles Lee: Fossils not definitely determinable but probably Devonian.

Grand View dolomite.—The Grand View dolomite is widely distributed in the Borah Peak quadrangle. It crops out along the front of the Lost River Range from the western border of the quadrangle almost to the divide at the head of Thousand Springs Valley and from Lone Cedar Creek to and beyond the southern border of the quadrangle. It is exposed on the northeast side of Mahogany Hill and on the slopes on both sides of Grouse Creek. Other outcrops lie in the southern part of the Donkey Hills and both northeast and northwest of Borah Peak.

The Grand View dolomite is similar to the Jefferson dolomite but contains proportionately fewer nearly black beds and fewer sandy beds. Much of the formation consists of moderately dark dolomite that weathers somewhat rusty. This rock is more distinctly bedded than most of the nearly black beds that characterize the Jefferson dolomite. The specimen of typical material, whose composition is given in Table 1, has no features either in chemical composition or in texture as viewed under the microscope to distinguish it from the Jefferson dolomite (Pl. 13, fig. 2).

The Grand View dolomite weathers sufficiently easily so that complete exposures of it are rare. The exposure afforded by the canyon of Grouse Creek in the northwestern part of the quadrangle is more suitable for measurement than most and may be considered to be fairly representative of the formation. Like all other formations in the area, the Grand View dolomite varies laterally in detail. It does not, however, exhibit such striking differences in different localities as those of the Jefferson dolomite. Data on the Grand View beds on the west side of the anticline in the canyon of Grouse Creek are given. The contact of the Grand View dolomite with the soft rocks of the overlying Three Forks limestone is not well exposed on either side of the anticline, and the total thickness may, therefore, be a little greater than that indicated in the following section.

SECTION OF GRAND VIEW DOLOMITE IN THE CANYON OF GROUSE CREEK

	Thickness Feet
Moderately light-gray dolomite, somewhat rusty; some beds distinctly banded, small solution cavities conspicuous	865
Dark dolomite, in distinct beds 1 to 3 feet thick. Forms cliffs 20 feet high. This rock resembles the nearly black dolomite of the Jefferson dolomite but is not quite so dark and is more perfectly bedded. It is slightly sandy	650
Alternating dark- and moderately light-gray dolomite, in beds 1 to 3 feet thick. Thin sandy beds that weather yellow are conspicuous	175
Alternating dark- and light-colored dolomite in beds 1 to 3 feet thick. Some of the dark units have an aggregate thickness of 15 feet, but most are thinner	205
Dark dolomite, closely similar to that of the Jefferson but a little thinner-bedded	80
Moderately light-gray dolomite. Some beds are rusty and sandy, some are almost as dark as those of the Jefferson	140
Total thickness	2115

Part of the Grand View dolomite in the Borah Peak quadrangle is a direct continuation of beds so mapped close to the type locality of the formation in the Bayhorse quadrangle (Ross, 1937, p. 27–29), and the correlation is thus unquestionable. The formation contains vestiges of organisms in numerous places in the Borah Peak quadrangle, but no determinable fossils were collected. The same is true of the beds in the Bayhorse quadrangle, but as the Grand View lies above the Jefferson dolomite and below the Three Forks limestone it is evidently of Upper Devonian age.

Three Forks limestone.—Throughout the Borah Peak quadrangle a thin formation, not recognized farther west, separates the Grand View dolomite from the Milligen formation. If beds of equivalent age exist in the Bayhorse region and areas south of it, they lack the distinctive lithologic features and abundant fossils found in the Borah Peak quadrangle and were included in the Milligen formation. As the formation here described resembles both lithologically and in age the Three Forks beds (Peale, 1893, p. 29–32) in Montana it may be called the Three Forks limestone.

The formation crops out in the valleys of Mill and Grouse creeks and near the top of the hill between Grouse Creek and Wino Basin. It is exposed in narrow bands at intervals along the southwest front of the Lost River Range. A remnant of it lies in a saddle in the ridge at the head of one of the forks of Mahogany Creek, and others lie along the upper reaches of Dry Creek. A band of it crops out also in the southern part of the Donkey Hills.

The Three Forks limestone in the Borah Peak quadrangle consists mainly of more or less argillaceous limestone with some calcareous shale and locally a little quartzite. Many of the beds, especially the more shaly ones, weather bright yellow. This color is recognizable from a distance even where the formation is thin and poorly exposed, as is commonly the case. The yellow weathered rock and the exceptionally well preserved fossils in certain beds are diagnostic of the unit and make it a useful horizon marker.

The Three Forks limestone varies markedly in the details of lithology and in thickness in different localities. The carbonate rocks in it appear to be everywhere calcareous in contrast to the dolomitic rocks in underlying formations, as is shown by the analyses in Table 1. The more argillaceous beds break readily in very thin plates parallel to the bedding. They are dark on fresh fracture but weather yellow. The formation is less resistant to erosion than the other Paleozoic formations of the region, so there is little opportunity for measurement or for the determination of stratigraphic details. The following section was studied by N. E. Chute on the south side of the valley of Grouse Creek. Thicknesses are estimated.

SECTION OF THE THREE FORKS LIMESTONE ON THE SPUR SOUTHWEST OF THE SECOND TRIBUTARY TO GROUSE CREEK FROM THE SOUTH ABOVE MILL CREEK

	Thickness Feet
Black, fine-grained argillaceous limestone in beds 3 to 8 inches thick, weathers gray with a yellow tinge	50+
Black, medium-grained limestone, mottled, in beds 3 to 12 inches thick	10
Black, medium-grained limestone, mottled with white areas on fresh surfaces, in beds 2 to 12 inches thick, rare fossils, weathers deep yellow with brown and red stains	15
Slightly calcareous shale with limestone beds 1 to 6 inches thick scattered through it. The shale becomes more calcareous upward. It is light gray on both fresh and weathered surfaces. About 5 feet above the base is a bed, 20 feet thick, with numerous, well-preserved fossils	60
Argillaceous limestone that weathers so readily that outcrops are rare. Gray to black on fresh surfaces. Weathers to a yellowish-brown soil	105
Limestone in thin slabs. Light yellowish-gray on fresh surfaces. Weathers to a yellowish buff with local red stains	10
Total thickness	250±

The Three Forks limestone crosses the ridge between Grouse Creek and Mill Creek in a saddle. Here it contains 200 to 250 feet of dark shaly limestone, not exposed, followed upward by 70 to 90 feet of slabby, dark-gray limestone with a massive bed 7-8 feet thick at the base. Between the limestone and the shale of the Milligen formation is 8 to 10 feet of bluish-gray quartzite in beds 6 to 18 inches thick. Similar quartzite is interbedded with Three Forks limestone in small outcrops south of Dry Canyon but is absent from most exposures of the formation.

Evidently the Three Forks limestone is about 250 to 350 feet thick in the general vicinity of Grouse Creek. On the ridge crest in unsurveyed sec. 11, T. 11 N., R. 21 E., the Three Forks limestone consists of about 50 feet of rusty quartzite, followed by about 250 feet of calcareous, highly fissile shale, with about 40 feet of banded quartzite on top. In most other parts of the Borah Peak quadrangle it is materially thinner. On the southwestern front of the Pahsimeroi Mountains the thickness is roughly 150 feet. Farther south, between Lone Cedar and Upper Cedar creeks, the formation is rarely more than 50 feet thick and locally is less than 30 feet thick. South of Upper Cedar Creek the formation again thickens somewhat. The uppermost of the three

Devonian units in Elbow Canyon in the southern part of the Lost River Range, east of Mackay, probably is essentially the equivalent of the Three Forks limestone of the Borah Peak quadrangle. This unit consists of about 100 feet of light-colored fossiliferous dolomite and limestone with intercalated shaly beds (Ross, 1934a, p. 964–965).

The differences in the thickness of the Three Forks limestone as mapped in different parts of the Borah Peak quadrangle may correspond to differences in the amount of material characteristic of the formation that was originally deposited. No evidence has been found of any break or angular discordance between the Three Forks and Milligen formations, and available data suggest that these formations are conformable and possibly gradational. Boundaries were necessarily mapped on the basis of lithology. It is entirely conceivable that nonfossiliferous carbonaceous shale, free from yellow color on weathered surfaces, mapped as belonging to the basal part of the Milligen formation, was deposited in Three Forks time.

The Three Forks limestone in most exposures contains lenses in which fossils are abundant and exceptionally well preserved. The following list gives the results of study by Edwin Kirk of collections from a number of these localities. The fossils listed indicate that the beds are of Three Forks (Upper Devonian) age.

Coll.—No. 2696. From the northwest side of the Rock Creek, on the west side of Lost River Range, about 1.5 miles west of the saddle between Rock and Mahogany creeks, outcrop within 100 to 125 feet vertically above Rock Creek. Collected September 3, 1935, by J. S. Williams: *Spirifir whitneyi* Hall var.

Coll.—No. 2703. From higher on slope in same locality as above collection. Collected September 3, 1935, by J. S. Williams: *Spirifer whitneyi* Hall var., *Leiorhynchus*, 2 sp., *Camarotoechia* sp.

Coll.—No. 2704. From weathered slope at same place as the above collection. Collected September 3, 1935, by J. S. Williams: *Leiorhynchus* sp., *Camarotoechia* sp., *Spirifer whitneyi* Hall var.

Coll. 2 of 9/4/35. From outcrops of same beds as those of the first two collections listed above. Collected September 4, 1935, by C. P. Ross: *Schizophoria striatula* var *australis* Kindle, *Camarotoechia* sp., *Spirifer whitneyi* Hall var.

Coll. 2 of 9/10/35. From about 6 feet above the water in Dry Creek not more than ¾ mile below the talus slope at the head of the main creek. Collected September 10, 1935, by J. S. Williams and C. P. Ross: *Spirifer whitneyi* var Hall, *Spirifer* cf. *raymondi* Haynes, *Leiorhynchus* cf. *madisonense* Haynes, *Productella* sp., *Athyris* sp., *Schizophoria striatula* var *australis* Kindle.

Coll. 3 of 9/11/35. From outcrop at edge of stream; Dry Creek about 2½ miles below its head. Collected September 11, 1935, by J. S. Williams. No definitely identified fossils but probably of Upper Devonian age.

BP 48. From cirque at head of Mahogany Creek. Collected August 3, 1935, by C. P. Ross: Small fragment of brachiopod, suggesting *Spirifer* cf. *disjunctus* type.

BP 49. From cirque at head of Mahogany Creek. Collected August 3, 1935, by C. P. Ross: *Spirifer* sp. There are several poorly preserved *Spirifers* in this lot. They apparently belong to the *Spirifer whitneyi* group, and the collection may safely be considered Upper Devonian.

BP 123. From the northeast slope of Borah Peak on ridge at the head of the Rock Creek at the west side of the Lost River Range. Collected September 3, 1935: *Spirifer* sp. Poorly preserved fragment but apparently of the *Spirifer whitneyi* type. (*Note:*—if this is Upper Devonian it indicates rock younger than was recognized in mapping. The locality is just below a large thrust fault so that a detached fault sliver might well be present.)

BP 523. From lumber road near Dry Canyon. Collected July 11, 1936, by C. P. Ross and N. E. Chute: *Spirifer whitneyi* Hall var., *Camarotoechia* sp., *Cleiothyridina* cf. *devonica* Raymond, *Leiorhynchus* cf. *madisonese* Haynes.

BP 708. From close to Leatherman Pass on the Pahsimeroi side, in the contorted mass of rocks in the thrust zone. Collected July 9, 1937, by C. P. Ross: *Rhipidomella* sp., *Productus* sp., *Leiorhynchus* sp., *Ambocoelia* sp.

Milligen formation.—The Milligen formation crops out almost continuously along the part of the southwest front of the Lost River Range included in the Borah Peak quadrangle. The principal gap in this line of exposures is between Lone Cedar and

Elkhorn creeks. The formation also crops out extensively on the south side of Grouse Creek, in the southern part of the Donkey Hills, and in an area between the head of the East Fork of the Pahsimeroi and Dry Creek. Smaller patches remain in other localities such as the flat-topped hill east of Wino Basin.

The Milligen formation in the Borah Peak quadrangle consists mainly of dark-gray to black carbonaceous shale. In most exposures this shale breaks readily into chips and plates with the flat sides parallel to the bedding. Locally, however, distinct slaty cleavage is developed. In such places the attitude of the bedding may be difficult or impossible to discern. Some beds are calcareous shale (Pl. 13, fig. 3). The three analyses in Table 1 represent the composition of most of the formation, but some beds contain more calcite.

The soft rock of this formation yields few exposures and in steep slopes is commonly covered by abundant talus from the overlying Brazer limestone (Pl. 3, fig. 1). These facts coupled with the close, contorted folds that are locally present hinder direct measurement of thickness. The thickness in most places is roughly 1000 feet (Pl. 1) in contrast to the estimated thickness of about 3000 feet in areas farther west (Ross, 1938, p. 31).

Here as in other areas the Milligen beds have yielded no diagnostic invertebrate fossils. They contain in numerous places macerated plant fragments, but none of those collected are sufficiently well preserved for identification. There can be little question, however, that like the similar material from the Bayhorse region studied by White (Ross, 1938, p. 32–33) they are of Carboniferous age. As the Milligen in the Borah Peak quadrangle is immediately above the Three Forks and below the Brazer limestone it is clearly of Mississippian age and more or less equivalent in age to the Madison limestone farther east.

Brazer limestone.—The Brazer limestone is widely distributed in the Borah Peak quadrangle and crops out over most of the higher parts of the Pahsimeroi Mountains. The ridges west of Thousand Springs Valley and the hills within that depression and the valley of Big Lost River are underlain by this limestone. It is exposed on Spring Hill Mountain, south of Double Springs Pass, and in and near the Donkey Hills and occupies much of the higher portion of the part of the Lost River Range between Leatherman Pass and the southern border of the quadrangle.

The formation is composed mainly of limestone, locally magnesian. Chert nodules and layers are abundant. A few beds are sandy. The lower 300 to 500 feet of the formation is much thinner-bedded and more siliceous than the rest. Much of this member is calcareous, but part of it is carbonaceous quartzite. Sample NC 73, whose analysis is given in Table 1, yielded only a trace of organic matter by the method employed, but sooty graphite is abundant in many beds. These resemble BP 582 which is one of the more carbonaceous of the specimens analyzed. In this basal member distinct parting planes parallel to the bedding are spaced at intervals of 2 to 6 inches and are crossed by numerous steep joints. Consequently the member commonly forms nearly perpendicular cliffs which yield such abundant talus that they are locally almost buried. In places, notably on the upper reaches of Long Lost Creek, the thin, basal beds are intricately contorted although the more massive limestone that overlies them is comparatively undisturbed (Pl. 3, fig. 1). They are dark gray to black and in most exposures are stained red by iron oxides on joint faces. In some respects the quartzitic parts of the basal member have closer lithologic resemblance to hard lenses in the Milligen than to the limestone that makes up most of the Brazer. However, most of it is calcareous, and all of it is sharply differentiated from the generally soft Milligen and grades upward into the typical Brazer. Hence the base of the hard beds constitutes the most satisfactory horizon at which to separate the two formations in mapping. The distinction is necessarily lithologic as both the typical Milligen and these hard beds are almost devoid of fossils.

The Brazer above the basal member is composed of limestone with occasional sandy beds. It is distinctly bedded in units that are commonly 1 to several feet thick. Joints are plentiful but less closely spaced than in the basal unit. The general appearance of the formation can be seen from Figure 1 of Plate 5. Most of the limestone is more or less dark bluish gray on fresh fracture, but some is black, and some is rather light gray. The color of weathered surfaces ranges from dark gray to nearly white but commonly is similar to that of Portland cement. Nearly all of the abundant chert is black on fresh fracture, but the surfaces of the nodules have gray coatings that are in places stained brown or red. Most of the chert is in irregular nodules, but some is in bands and lenses parallel to the bedding.

The texture and composition of the thick sequence of beds that makes up the Brazer limestone vary in many details. Figure 4 of Plate 13 shows that the quartzitic beds of the basal member are composed of rather angular quartz fragments set in a cement which is itself composed largely of finely ground quartz. The thin section photographed is from specimen NC 73, whose composition is shown in Table 1. The quartz grains average only about 0.04 mm. in diameter. The large white areas in the photograph are holes in the thin section. Figure 6 of Plate 13 illustrates one of the occasional beds of light-colored siliceous rock higher in the sequence. In this the light-colored grains are quartz, and the darker, mainly interstitial material, is calcite. The quartz grains are more distinctly water worn and, on the average, about 2½ times as large as in Figure 4 of Plate 13. As Figure 5 of Plate 13 indicates, the limestone beds are composed dominantly of crystalline aggregates of calcite whose grains vary markedly in size and shape.

In a few localities near the crest of the Lost River Range small masses of the Brazer limestone are rendered conspicuous by closely spaced, white subparallel bands. These consist of calcite, coarser and purer than that of the normal limestone but not so sharply separated from the latter as the calcite of ordinary veins. This variety of material is sometimes called "zebra rock" (Park and Cannon, 1943, p. 42–43; Crawford and Gibson, 1925, p. 36), a term that aptly describes its markings. It presumably results from recrystallization of calcite along roughly parallel shear planes.

The extensive exposures of bare Brazer limestone at high altitudes in the Lost River Ranges are commonly roughened as a result of etching by weathering. Some of the talus blocks that floor an ephemeral lake in a cirque nearly a mile southwest of Swauger Lakes are etched far more than any of the limestone observed in other localities. Some of the blocks in the same lake floor are essentially unetched. Figure 2 of Plate 3 illustrates the deep, unsystematic etch figures, and Table 1 shows that unetched limestone from here is a little more siliceous and magnesian than that which has been etched. This may account for the preferential etching. Why certain blocks at this one locality should be so much more deeply etched than similar material in similar situations in other parts of the quadrangle has not been learned.

The best opportunity to measure and study the Brazer limestone is afforded by the almost complete exposures of the formation in Leatherman Peak and adjacent mountains. The section summarized below is based on studies by J. S. Williams and the writer, mainly a short distance above the talus on the northern slopes of these mountains.

Section of the Brazer Limestone at Leatherman Peak

	Thickness Feet
Basal beds, dark, in part quartzitic, thin beds. (Coll. 7, 9/7/35 (26))	350±
Light medium-gray massive limestone with calcite veins beds 2–4 feet thick	7
Dark-gray thick-bedded limestone with chert nodules and bands, calcite veinlets (Coll. 1, 9/7/35 (20))	92
Black limestone in beds 2½ to 4 feet thick, chert and calcite veinlets decreasing upwards (Coll. 2, 9/7/35 (21) from lower part of unit)	57
Dark-gray limestone in 8–17 inch beds with little chert (Coll. 3, 9/7/35 (22))	10
Bluish-black limestone in beds 3–5 feet thick that unite to form cliffs 8–15 feet high. Has chert nodules and calcite veinlets (Coll. 4, 9/7/35 (23))	30
Light-gray limestone with some light and dark chert in beds 6 inches to 2 feet thick (Coll. 5, 9/7/35 (24))	21
Black fine-grained limestone with chert nodules and calcite veinlets in beds 1–4 feet thick (Coll. 6, 9/7/35 (25))	75
Single bed of light-gray limestone so full of fossils as to resemble coquina (Coll. 1, 9/8/35 (27))	2
Dark-gray to black limestone in 1½–5 foot beds that form 8–10 foot cliffs. Some beds contain abundant chert, which is black in the lower beds and light gray above, some calcite veinlets (Coll. 2, 9/5/35 (28))	79
Fine-grained black and gray limestone in alternate beds (Coll. 3, 9/8/35 (29))	132
Light-gray argillaceous limestone	1
Black, fine-grained limestone in 1–3-foot beds, with some chert and calcite	42
Light-gray limestone	2
Black limestone that weathers nearly white	13
Thin, fissile, black, argillaceous limestone with occasional beds of more massive, in part light-colored, limestone up to 2 feet thick (Covered by talus on the line of section but exposed above)	350±
Black to blue limestone with some dark chert, in 3–4-foot beds (Coll. 4, 9/8/35 (37))	15
Light- to medium-gray limestone with a few chert stringers in 3–5-foot beds. Weathers brownish	10
Black and gray limestone with chert nodules, especially in lower part, in 1–4-foot beds (Coll. 5, 6, 9/8/35 (38) (39))	106
Light-gray, fine-grained, sandy, banded limestone in beds 8 inches to 3 feet thick	19
Black limestone in beds less than a foot thick in lower part and 6–7 feet thick above, and 12–18 inches thick in upper part (Coll. 7, 9/8/35 (40) from upper part of unit)	101
Black limestone that weathers cream-colored, little chert	35
Black fine-grained limestone (Coll. 7, 9/8/35 (41))	4
Thick, massive black limestone beds with chert nodules, calcite veinlets, and at intervals chert beds, separated at intervals by weak, sandy beds 2–3 feet thick (Coll. 1, 9/9/35 (42))	101
Limestone similar to that just below but lighter-colored and with less chert (Coll. 2, 9/19/35 (43))	23
Black argillaceous and sandy limestone that weathers yellow, brown, and green (Coll. 3, 9/9/35 (44))	4
Black limestone with black chert locally plentiful	128
Massive, fine-grained gray limestone with black chert that increases markedly upward	52
Gray, argillaceous limestone that weathers tan (Coll. 4, 9/9/35 (45))	8
Dark-gray rather coarse limestone	3½

	Thickness Feet
Dark-brown argillaceous limestone	6
Dark-gray rather coarse limestone	4½
Brown argillaceous limestone in 3–5-foot beds	34
Blue limestone in 6–7-foot beds; alternates with slabby, gray, sandy limestone in 2–3-foot beds (Coll. 5, 9/9/35 (50) from base of unit)	150
Light- and dark-gray limestone. The darker beds are sandy. Beds are 2–4 feet thick. Little chert (Coll. 6, 9/9/35 (47))	423
Dark-gray and black thick-bedded limestone with some chert (Coll. 7, 9/9/35 (48))	110
Slabby, banded light- and dark-gray limestone	77
Light- and dark-gray, comparatively massive limestone	113
More or less highly siliceous limestone with some chert nodules, weathers brownish (Rocks beyond on line of traverse are poorly exposed and have been brecciated. Exposures in near-by cliffs indicate that there is fully 1000 feet of limestone in the Brazer stratigraphically above this point)	30
Total measured	2820
Additional estimate	1000±
	3820

The section given in some detail above may be summarized as follows:

Thin-bedded, siliceous basal beds	350 feet
Dominantly dark limestone in beds a few inches to a few feet thick	563 feet
Thin, fissile, black argillaceous limestone with a few more massive beds	350 feet
Limestone that tends to weather brownish and forms bluffs	654 feet
Dark rather thick-bedded limestone	683 feet
Alternating beds of light- and dark-gray limestone, in part thin-bedded	220 feet
Unmeasured part of section	1000 feet
	3820 feet

The above section indicates that the total thickness of the Brazer near Leatherman Peak is close to 4000 feet. In other parts of the quadrangle there are several places where 2000 feet or more of beds is present in continuous exposure and it is obvious that the total thickness is everywhere great. Umpleby (1917, p. 27) found partial sections containing 1000 to over 4000 feet of beds in different localities in the Lost River Range and estimated that the total thickness was probably more than 6000 feet. Most of the places he studied are south of the Borah Peak quadrangle.

The numerous collections made from the Brazer limestone in the Borah Peak quadrangle have not yet been studied in detail. In a general way they resemble those already reported from the Brazer in various parts of south-central Idaho (Ross, 1934, p. 978–989) and, like these, indicate that the formation is of Mississippian age, although some of the fossils in it have Pennsylvanian affinities. A few of these collections were obtained from localities in the Borah Peak quadrangle.

Some features of the collections made by J. S. Williams and the writer from beds included in the Brazer as mapped in the Borah Peak quadrangle (Pl. 1) are of so much interest that it is planned to devote a separate paper to their discussion. The nature of the problems raised by these collections may be inferred from a report by G. H. Girty (Ross, 1934, p. 992–993) on fossils collected by A. L. Anderson from the Arco quarry near the southern end of the Lost River Range. In his comments on Anderson's collection, Girty said that the faunal facies was unknown to him and "the affinities suggested by certain types are incompatible with one another. Brazer is suggested by some forms and Wells by others, and even Phosphoria cannot be disregarded." Reconnaissance studies suggest that the beds from which Anderson made his collection belong to the Brazer formation as mapped in the Borah Peak quadrangle farther north in the same mountain range. Apparent incompatibilities among the fossils such as those which puzzled Girty are present also in the collections made in the Borah Peak quadrangle.

Wood River formation.—The Wood River formation appears in the Borah Peak quadrangle only in a ridge in T. 8 N., R. 21 E. Here it consists of dark, locally calcareous quartzite such as that which composes much of the formation in neighboring areas (Ross, 1934, p. 985–993). No fossils were found in Wood River beds in the Borah Peak quadrangle, and the exposure is so isolated that the relations to other Paleozoic rocks cannot be determined. However, the lithologic characteristics of the beds are so distinctive that they are confidently regarded as Wood River formation which, in adjoining areas, has been found to be of Pennsylvanian age.

INTRUSIVE ROCKS

Summary note.—The Borah Peak quadrangle contains less intrusive igneous rock than most other areas of comparable size in central Idaho. However, a few small masses of quartz diorite are exposed in its northeastern corner, and lamprophyre and several kinds of fine-grained dikes related to the Challis volcanics are rather widely distributed. As the quartz diorite cuts ancient sedimentary rocks only, no clue as to its age is afforded within the quadrangle. It is thought to be related to the broadly similar rocks that were introduced in many places in the surrounding region late in Mesozoic time (Ross, 1936, p. 369–385). Small lamprophyric sills and dikes are widespread in presumable offshoots of some larger intrusion not yet exposed, possibly similar to the quartz diorite farther east. The other intrusive rocks in the quadrangle are mostly andesitic and basaltic dikes. All are similar to lava in the Challis volcanics, and most of them cut these flows. A few of the exceptionally fresh basaltic intrusions may be younger than the Challis volcanics, but most of the andesitic and basaltic intrusions are obviously related to that formation.

Quartz diorite.—Two small masses of quartz diorite are shown in the northeast corner of Plate 1. One of these is a dike that is mostly in sec. 9, T. 13 N., R. 24 E. The other is an irregular mass, generalized on the map, in and near the northwest corner of section 22 of the same township. The dike is much altered but consisted originally of irregular laths of oligoclase with considerable hornblende and biotite and a little interstitial quartz. Apatite is a conspicuous accessory mineral. The feldspar is somewhat sericitized, and the dark minerals have been extensively broken down into such minerals as chlorite and epidote. The fresher intrusive mass farther south contains fully 55 per cent of strongly zoned plagioclase (oligoclase to andesine). The plagioclase laths vary in length from a few tenths of a millimeter to over 2 mm., and some are grouped in imperfect rosettes. Grains of quartz and of perthitic potash feldspar occupy interstices between the plagioclase laths. There is about 15 per cent quartz and nearly 5 per cent potash feldspar, so that the rock approaches a granodiorite. The hornblende and biotite are intergrown and the biotite may be the

TABLE 1.—*Composition of representative samples of Paleozoic rocks from the Borah Peak quadrangle*

Analyses by R. C. Wells

	NC 61	NC 71	NC 58	NC 21	NC 22	NC 70	NC 14	BP 526	NC 72	BP 578	BP 582	NC 73	NC 74	NC 39	NC 40
Inorganic insoluble	2.93	.85	1.50	1.73	11.44	3.96	51.74	29.03	91.01	85.36	**90.87	99.49	2.89	20.19	56.06
Organic insoluble**	.03	.03	.10	.16	.04	.04	.17	.13	4.46	7.52	5.72	Trace	.19	.30	.39
$CaCO_3$	54.83	54.47	54.51	54.47	48.89	53.22	47.42	66.87	*.09	*1.72	*.44	None	96.13	78.16	40.72
$MgCO_3$	42.31	44.96	44.05	43.77	39.03	42.74	.66	1.13	†.05	†.09	Trace	None	1.06	Trace	1.25
P_2O_5	.02	.03	None	None	None	None	None	.17	.17	.81	.48	None	None	None	None
S	.01	.02	None	None	None	None	None	None	.04	.16	None	None	None	None	Trace
	100.13	100.36	100.17	100.13	99.40	99.96	99.99	97.33	95.82	95.66	97.51	99.49	100.27	98.65	98.42
C††		0.023							2.25	5.75	4.58			0.042	

* CaO.

† MgO.

** The organic matter reported here was that oxidized by hydrogen peroxide, and appearances indicated that there was some more organic matter in some of the samples.

†† Carbon determined by combustion.

NC 61. Dolomite in Kinnikinic quartzite, Upper west fork of Pahsimeroi River. Ordovician.

NC 71. Saturday Mountain formation, small butte 1.5 miles ENE of Mohogany Hill. Ordovician.

NC 58. Laketown dolomite from Rock Creek, tributary to west fork of Pahsimeroi River. Silurian.

NC 21. Jefferson dolomite, dark, from west side of Borah Peak at an elevation of about 11,000 feet. Upper Devonian.

NC 22. Jefferson dolomite, light, same locality.

NC 70. Grand View dolomite, station 545, Mill Creek near its mouth. Upper Devonian.

NC 14. Three Forks limestone, slabby, station 148, southern branch of Dry Canyon. Upper Devonian.

BP 526. Same formation, shaly.

NC 72. Massive argillite of the Milligen formation, station 547, saddle between Mill Creek and Dry Canyon. Mississippian.

BP 578. Fissile argillite of the Milligen formation, Wild Canyon. Mississippian.

BP 582. Black hard bed near top of the Milligen formation, Long Lost Creek. Mississippian.

NC 73. Siliceous rock in basal part of Brazer limestone, head of northwest fork of Dry Canyon.

NC 74. Brazer limestone from mouth of Rock Springs Canyon, station 549.

NC 39. Brazer limestone etched by lake water.

NC 40. Non-etched Brazer limestone.

younger. The rock contains about 15 per cent biotite and 10 per cent hornblende. Both are altered but by no means so extensively as in the dike above mentioned. The plagioclase, also, is far fresher in the irregular mass than it is in the dike. Apatite is rather plentiful. Carbonate and pyrite related to the veins in and near the irregular quartz diorite mass mentioned above are widely distributed through it but are abundant only close to the veins.

Lamprophyre.—Small bodies of lamprophyre are plentiful near the crest of the Lost River Range from the vicinity of Dickey Peak southeastward. Only the larger ones are shown on Plate 1, and these are necessarily somewhat exaggerated in size as most are only a few feet wide. Most are sills, but some are dikes, and a few are irregular. Many are bordered by white, coarsely recrystallized limestone, more conspicuous from a distance than the lamprophyre itself.

The rock is dark green except where stained brown by weathering. It tends to break down into roughly spherical bodies 10 to 15 mm. in average diameter. It consists mainly of biotite and plagioclase (sodic andesine), commonly with some quartz. Augite is locally present. Apatite and magnetite are common. Most of the feldspar is so much sericitized that its original composition is difficult to determine, and in some masses the dark minerals are also considerably altered.

The most striking feature of most of the lamprophyre masses is the peculiar texture that results in the spherical masses above mentioned. The feldspar is in markedly feathery, roughly radial masses which tend to form spheres rimmed with biotite. The more perfect of these constitute the spherical bodies that weather out of so many of these rocks. Commonly, however, the spheres are far from perfect. The mica flakes in many places are so heterogeneously oriented that little suggestion of regular rims is afforded by inspection of thin sections. Even where the biotite has distinctly circular arrangement, the tufts of feldspar within the circles have random orientation. The spherical masses, though imperfect, give a characteristic appearance to the lamprophyre of the Borah Peak quadrangle and appear to be essentially similar to the kugeln described by Milton (In preparation, 1947) in minette dikes from New Jersey.

Intrusives related to the Challis volcanics.—Most of the intrusive rocks associated with the Challis volcanics in the Borah Peak quadrangle, as in the area to the west (Ross, 1938, p. 68–69), are basalt and augite andesite. They are, however, much less abundant and smaller. Only the larger ones, mostly dikes of northwest trend, are shown on Plate 1. A few of the dikes are distinctly more alkalic than the rest. For example, the long dike that passes through the Rock of Ages east of Burnt Creek consists mainly of oligoclase with a little interstitial quartz and scattered small phenocrysts of hornblende and augite which together make up less than 10 per cent of the rock. The hornblende, in part chloritized, is the more abundant.

The small intrusion of black, flinty basalt that cuts Brazer limestone south of Dry Canyon in T. 12 N., R. 22 E., is so strikingly fresh as to suggest the possibility that it is related to flows of Quaternary age such as those exposed along Birch Creek (Stearns *et al.*, 1939, p. 231) east of the quadrangle here described. This rock is composed largely of thin laths of plagioclase, at least as calcic as bytownite, set in a brown semiopaque matrix. It contains phenocrysts of slightly chloritized augite and rare, partly altered olivine crystals.

TERTIARY STRATIFIED ROCKS

Challis volcanics.—The Tertiary volcanic strata in this part of Idaho are, as a whole, designated the Challis volcanics. In the Borah Peak quadrangle they are subdivided into the latite-andesite member, basalt and related flows, and the Germer tuffaceous member. Locally beds of conglomerate in the Germer tuffaceous member are mapped separately. These subdivisions correspond to those used in the adjacent Bayhorse quadrangle (Ross, 1938, p. 49–65), except that the rhyolite flows distinguished there have not been recognized in the Borah Peak quadrangle.

The latite-andesite member commonly constitutes the basal part of the formation but locally, as in the hills west of Garrett Rock in and near T. 10 N., R. 24 E., it overlies basalt. It forms exposures at intervals around the border of Pahsimeroi Valley and extends high into the range at the head of that valley, particularly along the West Fork of the Pahsimeroi River. The member is also exposed in the southwestern and southeastern corners of the quadrangle, where it forms hills that border the valleys of Big and Little Lost rivers respectively. In the northeastern corner of the quadrangle similar beds crop out around the head of the South Fork of Big Creek and on the borders of several minor valleys that drain eastward into Lemhi River. Basalt and related flows are conspicuous along the southwest border of the valley of the Pahsimeroi River and in places around the head of that depression. Small masses of similar rocks also crop out in the southwestern and southeastern parts of the quadrangle. The clastic beds grouped as the Germer tuffaceous member are nowhere abundant in the Borah Peak quadrangle. The principal exposures are in the northwestern corner of the quadrangle, where they constitute extensions of the large masses of similar beds that are widespread in the Bayhorse region (Ross, 1938, p. 53–58). Small masses of tuff and of sedimentary beds in the volcanic formation crop out in several other localities. Those large enough to show on Plate 1 include a lens, composed mainly of conglomerate, on the crest of the spur between the east and west forks of the Pahsimeroi River, and some tuff and related beds near the northwest corner of T. 10 N., R. 24 E. Lithologically similar tuffaceous beds crop out through the gravel in a small area in the hills west of the Goldberg School. Their relations to the gravel are not clear, but they are presumably older. Similarly the tuffaceous beds with which some lignite is associated, noted by Meinzer (1924, p. 11), in sec. 1, T. 13 N., R. 24 E., probably belong to the Challis volcanics, although most of the gravel on near-by slopes is now mapped as Donkey fanglomerate. The unconformity between the gravel and the volcanic rocks at this locality was suspected by Meinzer.

Latite-Andesite Member: The flows that compose the latite-andesite member in the Borah Peak quadrangle are essentially similar to those in the corresponding part of the Challis volcanics farther west (Ross, 1938, p. 51–53). They are moderately light-colored rocks in which shades of purple, gray, and green predominate. Most of them are inconspicuously porphyritic, and some, especially in the northeast part of the quadrangle, are flow-banded. Many are latite and quartz latite. The principal recognizable feldspar is alkalic plagioclase, but potash feldspar is presumably as abundant in the groundmass of these rocks as it is in the similar material in the Bayhorse region, that has been analyzed. Hornblende or biotite or both are commonly present in subordinate amounts, and many flows contain some quartz. Gray and red andesitic flows are commonly present. Locally, as in places in the vicinity of Burnt Creek, they are sufficiently abundant so that the distinction between the latite-andesite member and that composed mainly of more basic flows becomes somewhat arbitrary. Flow breccia, welded tuff, and sedimentary beds are intercalated in the latite-andesite member in several places but are nowhere as abundant as in many localities farther west.

Basalt and Related Flows: Most of the Challis volcanics in the Borah Peak quadrangle consists of nearly black and reddish flows of basalt and calcic andesite. Some of the flows mapped with this unit are similar to the more basic flows locally included in the latite-andesite member, and there are even occasional flows of distinctly latitic rock and some clastic beds. Detailed, large-scale mapping would, thus, result in more intricate subdivision than is indicated on Plate 1.

Most of the flows in this unit are brown and black fine-grained rocks with very small and inconspicuous feldspar phenocrysts. Many of the flows are somewhat amygdaloidal. Such flows consist mainly of plagioclase of the approximate composition of labradorite and augite. Some also contain a little altered olivine. The amygdules are generally filled with quartz or chalcedony; locally with calcite. Some flows, especially on and in the general vicinity of Squaw Tit, are brick red and scoriaceous. The vesicles are commonly filled with quartz, locally with some zeolite also. The rock is very fine-grained, and its phenocrysts are commonly visible only under the microscope. It is an andesite that consists mainly of moderately calcic plagioclase and a little augite, in part as phenocrysts. Some of the dark andesitic rocks interbedded with the basalt flows contain brown biotite instead of augite.

In Spring Hill Mountain clastic beds are locally intercalated in the basalt. These are principally rather coarse, green sandstone composed of poorly rounded grains of the minerals of the basalt and calcic andesite, together with some quartz and fragments of lava.

Germer Tuffaceous Member: The rocks that compose the Germer tuffaceous member in the Borah Peak quadrangle are lithologically identical to the corresponding beds farther west, described in some detail in the report on the Bayhorse region (Ross, 1938, p. 53–58). They are principally light-colored rocks composed largely of the products of explosive volcanism. Much of the material is sufficiently distinctly bedded to show that it has been sorted by water. The component grains came mainly from rhyolitic and latitic lava, together with quartz of detrital origin. Here and there are beds of welded tuff. Conglomerate is especially conspicuous along a branch of Meadow Creek in the northwest corner of the quadrangle but is present in other localities. The exposed thickness of tuffaceous beds within the quadrangle is nowhere much more than 500 feet.

Age of the Challis Volcanics: The clastic beds in the Challis volcanics in the Borah Peak quadrangle contain fragmentary plant remains in several places, but no diagnostic material was collected. The opinion expressed in the report on the Bayhorse region that "the Challis volcanics are possibly, if not probably, of Oligocene age and that they can hardly be younger than early Miocene," (Ross, 1938, p. 67) applies equally well to the rocks in the Borah Peak quadrangle.

Donkey fanglomerate.—The Donkey fanglomerate is here named for the Donkey Hills where it is exceptionally well displayed. Meinzer (1924) noted these beds both in the Donkey Hills and near the mouth of Big Creek but did not name them. The formation includes partially cemented material of alluvial character which is older than the alluvium of the modern valleys. It forms hills and spurs in and on the sides of valleys, and recent alluvium laps up against it. The principal exposure is west of Donkey Creek in the western part of T. 11 N., R. 24 E. This part of the Donkey Hills, which rises over 1000 feet above the level of the surrounding valley, is entirely composed of Donkey fanglomerate except that old quartzite and dolomite form small outcrops at the base of the hills in two places, and Garrett Rock and the near-by hills are composed of Challis volcanics. The outlying hills north of the Donkey Hills are also composed of this formation. The largest of these is near Goldburg School and has its summit in sec. 18, T. 12 N., R. 24 E. Near its base in sec. 12, T. 12 N., R. 23 E., there is an outcrop of tuffaceous material whose relation to the gravel is not clear. The lower parts of the mountain spurs on both sides of Big Creek are composed of Donkey fanglomerate, but, as they are largely covered with loose material, the contacts drawn on the map are necessarily somewhat arbitrary. The loose material consists in part of weathered Donkey fanglomerate, in part of fans, terraces, and related deposits of more recent alluvium. A small mass of Lemhi quartzite sticks through in the bank of Big Creek near the southern boundary of sec. 18, T. 13 N., R. 24 E., and Challis volcanics form most of the spur northwest of Mill Creek in and near sec. 1, T. 13 N., R. 23 E. The Donkey fanglomerate also forms spurs on the south side of the South Fork of Big Creek. Material on the lower slopes of the Pahsimeroi Mountains between Grouse and Meadow creeks has been assigned to the Donkey fanglomerate on Plate 1 although parts of the deposits that form the present surface are of more recent origin. The hummocky material in the saddle about a mile south of Rattlesnake Spring is doubtless of glacial origin, and there is also considerable hillwash and alluvium derived largely from the fanglomerate. The clastic material that mantles the slopes on the east side of upper Willow Creek in T. 10 N., R. 22 E., is assigned to the Donkey fanglomerate because it is so much more thoroughly consolidated than any of the younger materials. Very possibly slopes in other localities mapped as underlain by alluvium or by glacial deposits are composed of Donkey fanglomerate with thin veneers of more recent, unconsolidated material. Such localities include the steep slopes north of Big Gulch in T. 12 N., R. 24 and 25 E., the valley of Mahogany Creek in T. 10 N., R. 23 E., beneath the glacial deposits, and possibly part of the area along Vance Canyon on the southwest flank of the Lost River Range.

The Donkey fanglomerate is composed almost exclusively of rounded to subangular, poorly sorted gravel in an abundant cemented matrix composed largely of angular pebbles, sand, and dirt held in a mixture of quartz and calcite. In a few places porous calcareous material so predominates in the cement that the material resembles caliche. This is especially true in the vicinity of dolomite and limestone outcrops. Where fresh, the fanglomerate is a firm resistant rock, but the cement weathers so readily that outcrops are rare. In most places the slopes are mantled by loose gravel with cemented sand still clinging to some surfaces. This gravel and that in fresh outcrops is similar in degree of rounding and in range and size to that of the present alluvial fans and much of the valley fill. In those places in the eastern part of the quadrangle where the formation has been definitely recognized, however, the gravel is derived mainly from the Lemhi, Swauger, and Kinnikinic quartzites with some material from the Challis volcanics. In contrast, the valley fill along the Pahsimeroi is composed mainly of limestone and dolomite. This fact alone serves to discriminate sharply between the fanglomerate and the later fill on the peripheries of the Donkey Hills and their outliers except on the east where recent fans from the Lemhi Range, composed mainly of quartzite, are prevalent. Meinzer (1924, p. 12–14) called attention to this feature and used it as evidence that the Pahsimeroi in geologically recent time flowed through the gap at the north end of the main part of the Donkey Hills in sec. 20, T. 12 N., R. 24 E. In those parts of the Lost River Range where Donkey fanglomerate is present, as noted above, quartzite is so rare in the bedrock that calcareous and dolomitic rocks necessarily predominate in the alluvial deposits, irrespective of age.

The Donkey fanglomerate is clearly similar in origin to the alluvial deposits that are plentiful in all of the larger modern valleys but is distinctly older. It contains no known fossils except for fragments of fossil wood, which may have been derived from the Challis volcanics. It rests on, and contains pebbles of, the Challis volcanics. It is trenched by present streams, including some that have been glaciated, and forms hills that rise through the valley fill. Locally in the Lost River Range it is covered by the abundant glacial deposits. Along the South Fork of Big Creek in the Lemhi Range, the fanglomerate is on spurs between valleys with cirques at their heads. The fanglomerate is weathered and slumped and covered by a dense growth of jack pine. It is not possible to trace with assurance the effects of glaciation far below the cirques carved in bedrock, but the streamways seem clearly to have been eroded almost to their present level at the time of the last glaciation, and the fanglomerate is cut by, and apparently unrelated to, the stream valleys. Thus the Donkey fanglomerate seems to be post-Oligocene and pre-upper Pleistocene in age. Closer dating is impossible on the basis of information available in the Borah Peak quadrangle.

No rocks with which the Donkey fanglomerate appears to be comparable have been recognized in other parts of south-central Idaho except just east of the area here described. Similar deposits have, however, been reported from numerous places on the borders of the upper part of the Snake River Plain and in southeastern Idaho (Mansfield, 1927, p. 110–112; 1929, p. 30–37; Stearns *et al.*, 1939, p. 23–24). They are commonly correlated, with different degrees of certainty, with the Salt Lake formation of Pliocene (?) age. The nearest locality where such beds have been recognized is east of Medicine Lodge Creek in Clark County, 60 miles due east of the Donkey Hills. Here Stearns found ancient, dissected alluvial fans which, according to Mansfield, who inspected them in the company of Stearns, "might be correlated with the Salt Lake formation." Fossilized camel bone, which came either from these deposits or from the upper part of the rhyolite below them, was regarded by Gidley (Stearns *et al.*, 1939) as suggestive of Pliocene age. The analogy in character and position between the Donkey fanglomerate and the deposits near Medicine

Lodge Creek is so close as to suggest that the two are related. It must be realized, however, that alluvial fans and similar deposits must have been formed locally throughout this region during the long period since the close of Challis volcanism. Detached remnants of any such deposits old enough to be discordant with modern alluvium would resemble each other closely.

QUATERNARY DEPOSITS

Glacial deposits.—Clearly recognizable glacial deposits are exceptionally abundant in this quadrangle as compared to neighboring parts of Idaho. The areas so designated on Plate 1 are underlain by unconsolidated material much of which has the topographic form characteristic of such deposits. Glacial outwash merges with, and is in places overlain by, alluvium so that the distinction in mapping is necessarily somewhat arbitrary.

The largest masses of glacial material are in the valleys of Mahogany Creek and the West Fork of the Pahsimeroi, in Doublesprings Pass, and in the valleys in the northeast corner of the quadrangle. About 24 other masses have been mapped, and there are minor glacial dumps along the upper reaches of most of the mountain streams. Some of the deposits are close to the mountain borders.

The glacial deposits consist of a heterogeneous accumulation of poorly rounded and sorted material such as makes up similar deposits in mountain valleys in many regions. Most of them are sufficiently mantled with soil and vegetation so that details cannot be observed, and they can be distinguished from alluvial deposits only when the original topographic form is sufficiently well preserved to be recognizable. Frontal, lateral, and ground moraines are locally distinguishable. Outwash deposits, such as those on the lower reaches of Mahogany Creek, are indistinctly terraced. A large frontal moraine extends beyond the mountain border in sec. 10, T. 9 N., R. 22 E. This probably dammed Cedar Creek for a time. Lateral moraines are especially well preserved along the lower reaches of Christian Gulch but are present in many other places also. The large spur that lies mainly in unsurveyed sec. 17, T. 10 N., R. 23 E., is probably a lateral moraine. Near the northeast corner of section 17 the ridge cuts off all surface drainage from the valley on its northwest side. All water that escapes from this valley must do so underground as its channel ends in a funnel-like depression back of the ridge. The ridge has a notch in it but is not truncated by the stream in the manner that is incorrectly indicated by the contours on Plate 1. In several other places on this map the contours fail to depict the glacial features correctly. Hummocky deposits, doubtless mainly ground moraines, are especially conspicuous on Doublesprings Pass and in unsurveyed sec. 30, T. 10 N., R. 23 E. In the latter area, surface drainage is interrupted, and small undrained hollows are common, although not shown on Plate 1.

As the record of glaciation is even fresher and better preserved than it is in neighboring areas, it seems clear that most of it took place in the last, or Wisconsin, stage of Pleistocene glacial activity. No evidence has been found of older glacial deposits such as have been recognized in a few places farther west (Ross, 1929, p. 123–128), although it is supposed that the earlier glaciation also affected the Borah Peak quadrangle.

Alluvium.—In the Bayhorse region the Quaternary alluvium was divided into "older alluvium," "younger alluvium," and "flood plain alluvium" (Ross, 1938, p. 69-73). Deposits of comparable age and character exist in the Borah Peak quadrangle, but the three merge so that it is impractical to distinguish them on a map. Most of the alluvium here corresponds to the "older alluvium" of the Bayhorse region, except that glacial deposits which were grouped with it in that area have, in general, been mapped separately in the Borah Peak quadrangle. Much of the material that veneers surfaces between the lower sets of terrace banks shown on Plate 1 corresponds to "younger alluvium." In some stretches such material has been scoured away, and in many places material of similar age is spread over fans and merges with older accumulations. In places along the Pahsimeroi and Lost rivers narrow bands of "flood plain alluvium," mostly silt, might have been distinguished on the map.

Much the greater part of the Quaternary alluvium in the Borah Peak quadrangle floors the great intermontane valleys. However, either alluvium or glacial deposits extend in mappable masses far into the mountains along each of the major streamways. At Doublesprings Pass such deposits extend entirely across the mountains, and in several other places they reach as far as the headwater cirques.

Most of the Quaternary alluvium in the Borah Peak quadrangle consists of coarse gravel and boulders, poorly sorted and rounded, with sand in the interstices. The deposits are all compacted, and most of them are somewhat cemented, largely by caliche. Steep banks and shallow caves are maintained in them. The floors of some of the recent channels contain thin deposits of gravel, sand, and silt.

Travertine.—Travertine in bodies of appreciable size has been found in this quadrangle only along the valley of Mill Creek just below the sharp bend in that stream near the northwest corner of unsurveyed T. 12 N., R. 22 E. It is crudely banded, highly porous calcareous material associated with the alluvium. It closely resembles the mass in Spar Canyon in the Bayhorse quadrangle (Ross, 1938, p. 64) and those in the valleys of Elkhorn, Milligen, and other creeks in the Hailey quadrangle (Umpleby, Westgate and Ross, 1930, p. 117). Like these, it is presumably a product of spring water in geologically rather recent time.

Landslides.—Landslides are numerous on the steep slopes of this quadrangle. A dozen of the larger ones are shown on Plate 1, mostly in the southern part of the quadrangle. Several of the larger slides are in areas underlain by Challis volcanics, probably because these rocks weather to clay minerals comparatively readily. Some, like the one west of Vance Canyon, may represent collapse of glacial deposits perched high on mountain sides.

STRUCTURE

REGIONAL SETTING

Pre-Tertiary deformation.—In the latitude of the Borah Peak quadrangle the border of the Idaho batholith, one of the dominant structural features of central Idaho, is slightly east of longitude 115°. Immediately east of this some 30,000 feet of beds, largely of Paleozoic age, were markedly deformed during the disturbances that preceded the intrusion, and redeformed in genetic association with the emplacement of the batholith at its present level (Umpleby, Westgate, and Ross, 1930, p. 61–71;

Ross, 1936, p. 376–381; 1938, p. 73–83). Between this area of intricately folded and faulted rocks and the Borah Peak quadrangle farther east is a broad expanse in which the pre-Tertiary deformation was less intense. Parts of this zone have been studied only in reconnaissance fashion, and large areas are blanketed by the Challis volcanics and later rocks, so that details are lacking.

In the Borah Peak quadrangle and adjacent areas, the Paleozoic strata, with an aggregate thickness of about 20,000 feet, were deformed in response to two separate disturbances in a manner that recalls the structure immediately east of the batholith. However, the folds are more numerous and closely spaced. The Paleozoic strata rest on Belt rocks that have been previously and less intricately folded. In this area, unlike the other areas mentioned, the massive, resistant Belt rocks in places are at such high altitudes as to be widely exposed in present mountain ranges.

Still farther east and southeast, beyond the Snake River Plain with its blanket of Tertiary and later rocks, the mountains are built up of intricately and irregularly folded and faulted rocks that range from pre-Cambrian to Lower Cretaceous and have an aggregate thickness in excess of 40,000 feet, of which some 60 per cent is of Mesozoic age. Farther east, in Wyoming, the thickness and relative proportion of Mesozoic beds are still greater (Wilmarth, 1925). The great assemblage of Paleozoic and Mesozoic stratified rocks in southeastern Idaho contains some unconformities but in general was deformed as a unit at about the beginning of Tertiary time (Mansfield, 1927, p. 48–107, 131–167, 173–199; 1929, p. 46–62; Gardner, 1944, p. 5–11). The western border of present exposures of Mesozoic stratified rocks extends from near the southeastern corner of Idaho northwestward to the southeastern part of the Beaverhead Mountains (Ross and Forrester, 1947) (Fig. 1), and thence into Montana approximately along 113° longitude (Andrews, Lambert, and Stose, 1944). In these Montana localities the Mesozoic beds rest on Paleozoic formations which have a smaller aggregate thickness (Emmons and Calkins, 1913, p. 49–82; Winchell, 1914, p. 23–28; Shenon, 1931, p. 14–16, 45–49) than those in the parts of Idaho commented on above.

Mesozoic sedimentary rocks may have extended originally somewhat west of the margin of present exposures, but probably none of them ever extended into the area of the present Borah Peak quadrangle.

On the contrary, it is probable, as Mansfield (1927, p. 184–199) has pointed out, that there were mountains in south-central Idaho when the Mesozoic seas covered more eastern parts of the state. The record in the Borah Peak quadrangle indicates that this area may have received no marine deposits since late Carboniferous time. The Wood River formation (Pennsylvanian), so thick farther west (Ross, 1930, p. 29–34), is scantily represented here, and neither the Permian? Casto volcanics (Ross, 1934, p. 28–35) nor other rocks of possible Permian age have been recognized in or near the quadrangle.

These data are in accord with the general concept of eastward migration of deformation and intrusion during the latter part of Mesozoic time (Lindgren, 1915, p. 261–263; Thom, 1923, p. 4–7; Ross, 1928, p. 691) from the Pacific coast into Montana and Wyoming. Applied to the Borah Peak quadrangle, this concept suggests that both the deformative episodes that have left their record on the Paleozoic strata are of late Mesozoic, probably Cretaceous, age. They may each have taken place slightly later than the corresponding events close to the batholith, where the greatest thickness of readily deformable beds in south-central Idaho was situated. In harmony with present concepts in regard to the age of the batholith (Ross, 1936, p. 382–383; Ross and Forrester, in preparation, 1947), the two deformations near the batholith may have taken place in Jurassic and Cretaceous time, respectively. On the other hand, the major deformation in southeastern Idaho came at the close of the Cretaceous period (Mansfield, 1927, p. 198–199) after a thickness of structurally weak strata greater than that on the border of the batholith had accumulated.

Tertiary deformation.—The pattern of mid-Tertiary deformation in south-central Idaho is fundamentally different from that of the Mesozoic structures discussed above, although certain features of the two are almost coincident. The major lineament is the zone of deformation and intrusion which extends about N. 45° E. from north of Boise diagonally across central Idaho, past Shoup, to the Montana boundary (Ross, 1933, p. 269). The distribution of rocks indicated on the new geologic map of Montana (Andrews *et al.*, 1944) support the idea that this lineament may persist for a long distance into Montana. Similar but much shorter lineaments with northwesterly trends appear to be present in the Lava Creek district, Butte County (Anderson, 1929, p. 26–27), and in the vicinity of Silver City, Owyhee County (Piper, 1926, p. 37–51). Structural features of similar trends have been noted in enough localities in south-central Idaho (Ross, 1925, p. 11–14; 1934, p. 77–83; 1938, p. 82–87; Umpleby *et al.*, 1930, p. 66–73) to indicate a conjugate set of strains throughout this region. The average trenches are N. 45° E. and N. 35° W., but departures of as much as 20° from these averages exist locally. Where the faults, folds, and intrusive masses that result from the strains can be dated, they are somewhat later than most of the Challis volcanics (Oligocene or Miocene). In some places, as in the Wood River region, many of the strains are reflected only in a stream pattern developed along lines of fracture in the rocks along which displacements are so minor that they are rarely detectable. Some faults are revivals of fractures formed during the disturbances of Mesozoic time.

The thick Challis volcanics have not been subjected to sufficient tangential compression on a regional scale to form many well-defined folds. Over much of south-central Idaho the volcanics have been warped and tilted, but only here and there do they show distinct, systematically arranged fold axes. In the Borah Peak quadrangle the Challis volcanics have been extensively dissected and mantled by later deposits, but available evidence points to the former presence of somewhat ill-defined anticlines with axes approximately accordant in trend and position with the higher parts of the existing mountain ranges. Such anticlines would belong with the structures of N. 35° W. average trend in the regional pattern and would be similar to some of the most pronounced folds in the Challis volcanics in the Bayhorse region (Ross, 1938, Fig. 7) west of this quadrangle.

The geomorphic history of south-central Idaho indicates that some crustal disturbance has continued intermittently up to the present. Earthquakes still occur occasionally. Faults formed later than the period of deformation referred to in the preceding paragraph have been postulated in several localities (Anderson, 1934, p. 17–28; Capps, 1941) mainly west of the Idaho batholith, where post-Challis rocks are more abundant. In the Borah Peak quadrangle there has probably been some renewal of movement on old faults, and some faults that are associated with modern topographic features may have originated late in Tertiary time.

The summaries given above call attention to the salient features of the geologic structure of south-central Idaho and their relationships to each other and, in particular, to the Borah Peak quadrangle. Available data on the structure of the Borah Peak quadrangle are presented in some detail.

FOLDS IN THE OLD ROCKS

The thick, dominantly quartzitic units of pre-Cambrian age that compose most of the part of the Lemhi Range within the Borah Peak quadrangle and the similar beds in the northern part of the Donkey Hills have been arched into broad folds with minor local crenulations. The formations are so thick and contain so few reliable horizon markers that details of the structure are difficult to trace. Also there are large areas, especially among those underlain by the Lemhi quartzite, where exposures are so few and so poor that structural details have not been learned. Where outcrops are small and weathered, bedding planes and schistose cleavage cannot be distinguished.

The average strike is nearly due north, although there are wide local departures from this average. Most of the dips are eastward. The inclination ranges from 20° to vertical but in most places averages 40° or a little more. The map records numerous departures from the average attitude of the beds, and the mantle of hillside wash on most of the gentler slopes doubtless conceals many others. These result from minor folds and local crenulations. A few of the minor folds, such as the anticline near the mouth of the South Fork of Big Creek, are fairly well exposed. Attempts to follow individual folds along the strike suggest that they are merely the results of local crumpling and that none persist far.

The pre-Cambrian quartzitic rocks have an imperfectly developed schistosity that is rarely conspicuous except in the more impure beds in the Lemhi quartzite. The strike of the schistosity northwest, and its dip is 25° and more southwest. Thus, while the average strike of the beds is nearly north instead of northwest, as in the Lost River Mountains, the schistosity is nearly parallel to the folds in that range. The major folds in the part of the Lemhi Range near Salmon northwest of the quadrangle likewise trend nearly north (Ross, 1925, p. 11–14) with dips of 35° and less. This part of the range trends nearly north, although the Lemhi Range as a whole trends northwest. The attitude of the schistosity near Salmon has been recorded in so few places that no generalization is warranted. The copper deposits in that region, many of which are in broad shear zones, have an average trend of about N. 49° W. (Ross, 1925, p. 16–18). It is suggested that the open folds of northerly trend throughout the range originated either in late pre-Cambrian or early Paleozoic time and that the structural features of northwesterly trend in the old rocks represent effects of the much later deformation in which the Paleozoic rocks were folded. The old rocks are so thoroughly competent that structures once formed in them would not be easily obliterated by later movements. It has long been known that the Belt rocks of western Montana were deformed before the Cambrian beds were deposited upon them (Walcott, 1899, p. 199–244; Emmons and Calkins, 1913, p. 50; Deiss, 1935, p. 95–124). The folds in the quartzites of the Lemhi Range are probably of similar date. On the other hand, as no Cambrian beds have been recognized here, the deformation might be as late as that which produced a post-Cambrian unconformity in southeastern Idaho (Mansfield, 1927, p. 181; Ross, 1925, p. 12) and neighboring regions.

FOLDS IN THE PALEOZOIC BEDS

The Paleozoic rocks throughout the quadrangle are intensely folded. The folds are, in general, closely spaced, have northwest trends, and most of them are more or less overturned toward the northeast. Some folds, mostly minor, are overturned in the opposite direction. Local variations in axial trend which cause one anticline to impinge on another, and other features suggest successive pulses of deformation. The faults described later in the report contribute in places to the complexity of the folding. The widespread but small-scale crenulations that attract the attention of any observer are regarded as the results of late-stage contortion of the beds under light load.

The principal features of the folds in the Paleozoic rocks are brought out on Plate 1 by lines that represent, in somewhat generalized fashion, the intersections of the axial planes with the topography. Minor folds are not shown, and the data available do not everywhere permit complete delineation. In some of the places where the trace of an axial plane is stopped on the map the anticline concerned has split up into indefinite minor folds; in others absence of the line on the map simply results from inadequate information. Most of the lines were sketched from distant vantage points and checked by observations at close range. Where exposures did not permit such sketching, some lines were drawn on the basis of observations on scattered outcrops. The latter method, by itself, is comparatively unsatisfactory because the information gathered is rarely adequate in detail, especially where the folds are complicated by minor wrinkles and by faults of different kinds.

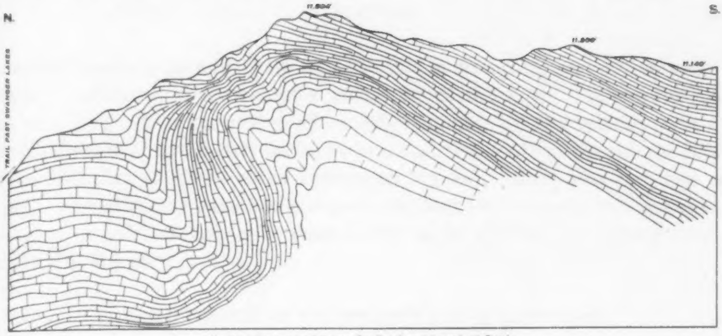
The folds in the hills in and near T. 10 N., R. 21 E., southwest of the main range, constitute part of a zone of moderate deformation, most of which is in the Bayhorse quadrangle (Ross, 1938, p. 75, Pl. 3A). This zone has a width of fully 35 miles between the intricately compressed folds of the White Cloud Peaks, immediately east of the border of the Idaho batholith, and the overturned folds of the Lost River Range.

In the part of the Lost River Range northwest of Mahogany Creek the average trend of the axial planes is nearly N. 30° W., although a few swing locally much farther to the west. The details of the folds cannot be adequately shown on the geologic map and structure sections on Plate 1. Their character can be judged from the sections in Plate 4, which are based on sketches made in the field. All these sections, except A, are from the part of the quadrangle described in the present paragraph. Irregularities of all sorts are common, and in places the folds change markedly within short distances along the strike. This is illustrated by the contrast between sections C and D, Plate 4. Figure 1 of Plate 5 shows folds in the same part of the quadrangle which are especially characteristic of the more thoroughly disturbed beds. The sharper bends are sufficiently discordant with the main folds as to suggest that they are younger, an impression which is strengthened by similar features in many other exposures and by the erratic distribution of the crumpling.

From Mahogany Creek to the West Fork of the Pahsimeroi the structure is so complicated by faults that few folds can be traced. Figure 2 of Plate 5 shows an example of the local contortion close to thrust planes in this area. Southeast of the thrust zone the axial planes trend on the average N. 40° W. Here, as in the northern part of the range, certain folds locally strike much more westerly than the average. In places, notably in the general vicinity of Swauger Lakes, axial planes of more nearly westerly trend cut across those of average trend. In this area the anticlines are crowded much closer together than is common, and the beds are locally intensely crumpled. Some folds are recumbent. Similarly contorted strata are present throughout the range, but crenulation in the Brazer beds is more marked and widespread in the area between Dry and Long Lost creeks than in any other area of comparable size within the quadrangle. Both the relations of the axial planes as mapped, and the appearance of the folds in the field suggest strongly that folds (trending about N. 40° W.) have suffered additional deformation as a result of renewed pressure from more southerly directions. Plate 4 shows an overturned anticline in this part of the region, which has marked secondary crumpling along the crest. Figures 1 and 2 of Plate 6 are also illustrative of folds here.

Most of the sections across the range on Plate 1 show that the structure is essentially an anticlinorium. The Paleozoic rocks are not merely folded into closely spaced, contorted anticlines: the mass as a whole has been arched. The somewhat poorly defined crest of the compound arch lies in general nearer the southwestern than the northeastern border of the range. The overturned folds sufficiently large to be conspicuous on the sections are principally northeast of the crest of the anticlinorium, although contorted, broken, and overturned beds are locally present throughout the range. The effect suggests that the tightly folded beds were first bent into an anticlinorium, and that, later, renewed movement tended to overturn the folds on its northeastern side.

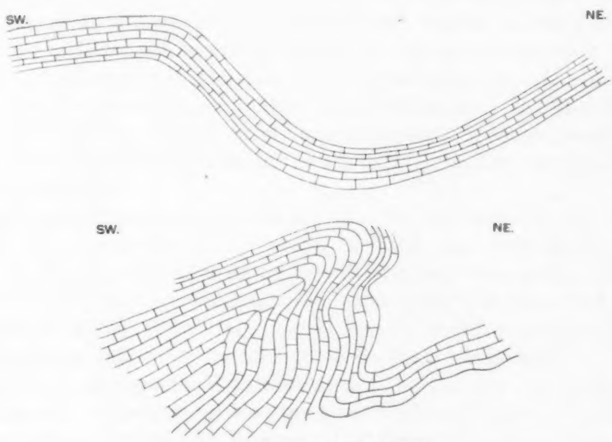
The relations between the tight, contorted folds in Kinnikinic and later formations in the Lost River Range and the more open folds in the pre-Cambrian rocks of the Lemhi Range are obscured by the broad alluvium-floored expanse between the two ranges. In general, however, the conclusion seems obvious that the massive, quartzitic pre-Cambrian rocks acted as an almost unyielding buttress against which the less resistant Paleozoic formations impinged. Where the Paleozoic rocks are supported by the old, massive rocks at comparatively slight depth, as in the Donkey Hills, deformation is less severe. In contrast, in parts of the Lemhi Range south of the Borah Peak quadrangle where pre-Cambrian rocks are not exposed, the Ordovician and later Paleozoic rocks are intensely deformed. The Dome mining district furnishes an example (Ross, 1933b, p. 6–7). Apparently the forces that deformed



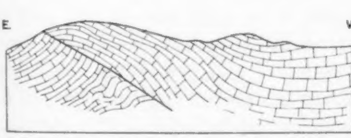
A. View along crest between Dry Creek and Long Lost Creek.

B. Near east boundary of Sec. 13, T. 10 N., R. 22 E.

C. Ridge crest between two branches of Christian Gulch, in and near unsurveyed Sec. 16, T. 11 N., R. 22 E.

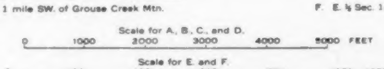


D. Two sections of same fold. Lower one is in cirque just SE. of upper one. Upper view is near the SE. cor. of T. 10 N., R. 22 E.



E. View in the head of a creek 1 mile SW. of Grouse Creek Mtn.

F. E. ½ Sec. 12, T. 10 N., R. 22 E.



SECTIONS TO ILLUSTRATE THE CHARACTER OF THE FOLDS IN LOST RIVER RANGE.

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the younger rocks, especially those that resulted in crumpling and overturning, were effective at relatively shallow depths within the earth's crust. Where the massive rocks were deep, their protective effect was minimized. The relative ages of the rocks involved is a particularly useful measure of their depth at the time of deformation, as Mesozoic stratified rocks were never present. Beds near the base of the Paleozoic sequence may have had a superincumbent load of over 10,000 feet of rock at the time of deformation, while those in the upper part of the Brazer may have been close to the surface.

MINOR RESULTS OF DEFORMATION UNDER LIGHT LOAD

Many of the smaller folds and crumples in the Paleozoic differ little except in size from the major folds and were formed concomitantly with the latter. Others, particularly in the pre-Mississippian rocks, were formed incidental to overthrusting. However, a large number of very conspicuous, though commonly small, folds appear to have less direct relation to the larger structural features. Most folds of this kind are in the Brazer limestone. Characteristic features include the sporadic distribution of intensely contorted masses, the discontinuity of individual beds within such masses, and the apparent tendency for the beds to spring away from each other where tightly bent, much as cards in a pile might do if force were exerted against their opposite edges. These folds are not necessarily parallel to the major structures. They are present throughout the areas underlain by Brazer limestone but are especially conspicuous in the mountains between Dry and Long Lost creeks. In Figure 1 of Plate 6 the overturned anticline may be merely a small example of the regional folds, but the nearly vertical, narrow anticline in the left part of the view has no counterpart among the major folds.

Local folds are characterized by discontinuity of the beds (Pl. 4A; Pls. 5, 6). A segment of a particular bed or group of beds may end against a minor fracture. In places contorted material sprouts abruptly from gently folded rock. Crumpled beds may butt into comparatively undisturbed rock above and be underlain by similarly slightly flexed beds. In general the crumples are erratic, limited, and without known relation to the strength of the materials involved.

In gently flexed exposures the Brazer limestone is, for the most part, rather massive with inconspicuous separation between the beds. Where sharply bent, the beds become more distinct, and massive limestone 1 or more feet thick is separated from adjacent beds by sheared material that yields to erosion with comparative ease. Commonly the top of a particular bed is much farther from the top of the next underlying bed in the apex of a fold than it is on the flanks (Pls. 4, 5, 6). The individual beds tend to be thickened at the apexes of the folds, but this is a comparatively minor feature. The unsupported part of each bed in the apex of a fold is pinched in so that the base on one flank of the fold is nearly or quite in contact with the base of the same bed on the opposite flank of the fold. There may or may not be transverse fracture at the crest.

Such features suggest that part of the deformation results from erratically applied, localized forces, and that gliding along bedding planes and more or less irregular fractures, especially at the points of greatest bending, contributed largely to the complexity of the structure. The rocks are so nearly of uniform strength that localized, unsystematic forces seem required in order to explain the results observed.

Conspicuous and highly irregular deformation of limestone has been reported from many regions in which the rocks have been deeply buried and subjected to high pressures and elevated temperatures. The results of the process under these conditions are intricate, commonly recumbent folds in which flowage is evident. The beds may have been so stretched in places as to have been pulled apart, but fractures that result from inability to bend are uncommon. This kind of folding, in which the plasticity of the limestone is the conspicuous feature, has been illustrated and discussed, for example, by Newland (1917, p. 145–148), Bain (1931, p. 503–530), and Balk (1936, p. 717–724; Figs. 21–23; Pl. 11) among many. The structures in the Borah Peak quadrangle have some resemblance to these, but the differences seem even more striking. Much of the more intricate crumpling is local and apparently haphazard. Evidence that the elastic limit was exceeded is everywhere plentiful. Such features are believed to result from deformation at much shallower depths than in such localities as those cited by Newland, Bain, and Balk in New York. The tangential pressure was marked, but neither was the superincumbent load great nor the temperature high. The Brazer limestone is moderately thick, but at present no pre-Tertiary formation overlies it. Some equivalent of at least part of the thick Wood River formation may once have extended far enough east to cover the site of the Lost River Range, but, as no remnant of any such beds or of younger beds has been preserved in the tightly folded and much faulted rocks of the part of that range here mapped, it seems improbable that any considerable thickness ever existed. If it had, some fragment of the post-Brazer unit should have been preserved in the bight of a syncline or in a down-faulted block. Thus the folds probably formed under relatively thin cover. The thickness of the Brazer limestone is close to 4000 feet, and, where tightly folded, the formation may well have extended locally through a vertical range of more than 6000 feet. Consequently, some of the local, intensely contorted masses in that formation may have been covered by as much as a mile of rock even if the major folds extended essentially to the surface of the ground as it then existed.

Some plastic deformation, including flowage, has obviously taken place throughout the sequence of Paleozoic beds, both in the major folds and in the localized contorted masses. This is by no means incompatible with the concept that much of this rock was under light vertical load when deformed. Crystalline limestone has plastic properties even in quarried slabs. Much or all of the deformation in this region took place while great tangential pressures were being exerted. The redistribution of material shown by variations in the thicknesses of the beds may have resulted partly from solution and recrystallization. The locally abundant calcite veinlets and the "zebra rock" conspicuous in some of the more intensely deformed limestone show that conditions favorable to redistribution of calcium carbonate existed at the time of deformation. Recrystallization with comparatively little transportation of material may have been one of the potent factors in the blending process that makes it difficult to trace some of the contorted beds.

FIGURE 1. FOLDED BRAZER LIMESTONE
In head of middle fork of Mahogany Creek. Taken from the ¼ corner on the east border of sec. 24, T.10N., R. 22E. Retouched to bring out structure.

FIGURE 2. JEFFERSON DOLOMITE CRUMPLED ALONG THRUST FAULT
Near head of Rock Creek that is tributary to the Pahsimeroi. Retouched to bring out structure.

FOLDS IN BRAZER LIMESTONE AND JEFFERSON DOLOMITE

Figure 1. Contorted Brazer Limestone
In cirque wall west of 10,530-foot peak south of Swauger Lakes. Note isolated secondary vertical anticline. Retouched to bring out structure.

Figure 2. Contorted Brazer Limestone
East of the 10,530-foot peak south of Swauger Lakes. Note that an asymmetric anticline has been in part tipped back to a vertical position. Retouched to bring out structure.

CONTORTED BRAZER LIMESTONE

OVERTHRUSTS

The Lost River Range contains many overthrust faults, mostly of small displacement and rather steep dip. They are of two general kinds, although the distinction between the two is not clear in all cases, and they may be genetically related. One kind consists of thrusts at and near the apexes of overturned folds. The other

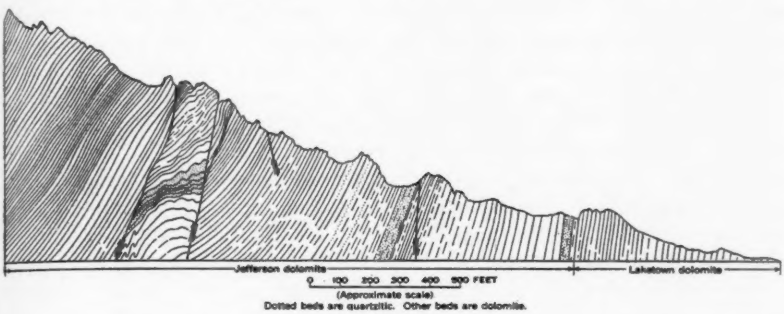

FIGURE 3.—*Steep thrust fault in Jefferson dolomite along a ridge between Mahogany and Rock creeks*

Minor normal faults are also shown. The section is based on a field sketch and a photograph.

consists of more gently dipping thrusts of larger displacement, without direct relation to the folds.

Thrusts associated with the folds are plentiful throughout the range. One or more is visible in nearly every exposure of an asymmetric anticline. The thrust plane commonly has an attitude similar to that of the axial plane of the anticline, but in many places its dip is somewhat steeper. In most instances the displacement ranges from a few feet to a few score, or rarely a few hundred feet. As can be seen from Plate 4, F and G, such thrusts distort the anticlines, but few disguise the original character of the fold. These thrusts trend northwest, approximately parallel to the folds, and dip southwest at angles up to 75°, locally even steeper.

Here and there thrusts similar in attitude to those above described have no obvious connection with anticlines. The ridges between Mahogany Creek and the Rock Creek tributary to the Pahsimeroi reveal several examples of such thrusts. Figure 3 shows one of these. The rock in these ridges, especially the ridge that borders the valley of Mahogany Creek, has been crumpled and contains a number of minor tight folds. Apparently the steep thrusts, commonly almost parallel to the bedding planes, are related to the folds, even though they do not everywhere lie near the apexes of anticlines. This lack of direct relation to the folds may result from greater displacements than those of the thrusts first described. Distortions in the beds close to such thrusts are more conspicuous than in the neighborhood of those that merely crack the crests of anticlines, which is in accord with the possibility of greater displacement. On the whole, thrusts of the kinds above described seem to be merely incidental to the folds. They represent failure of the rocks to maintain their plasticity during folding.

The second variety of overthurst, marked by comparatively low inclination and evidence of greater displacement, is exemplified by the thrusts that underlie Borah Peak and the peak west of Leatherman Pass. These two thrusts are separated by cross faults and do not affect quite the same rocks but in attitude and position are so similar as to imply kinship. The thrust under Borah Peak is exposed along a curved line about 3 miles long on the northeast flank of the range and is cut off at both ends by two parallel faults. The latter have so much horizontal displacement as to resemble tear faults. This interpretation is accepted though these faults belong to an extensive zone of normal faults, some of which have had movements so recent as to affect the Challis volcanics. The thrust itself is marked wherever exposed by a zone of intricately contorted and broken rock with vertical dimensions of 20 feet and more. Veins of coarsely crystalline white calcite several feet wide draw attention to the disturbed zone. The difference in general appearance between the Jefferson dolomite below the thrust and the Laketown dolomite of the overriding block is so small that the thrust would be difficult to map, if it were not for this zone of marked disturbance. The thrust is of considerable magnitude. As indicated on section CC′ of Plate 1, the thrust block has moved at least a mile eastward over the folded Devonian and older beds. The fault surface appears to dip 15°–20° W. or SW. and is distinctly curved.

The similar thrust fault near Leatherman Pass ends on the northwest against one of the tear faults that bound the thrust near Borah Peak. Kinnikinic quartzite lies both above and below the thrust, and the zone of disturbance along the fault is occupied by intricately deformed beds that are in part of Devonian age. The upper contact of the zone of disturbance (Pl. 7, fig. 1) is an irregularly curved surface which is bent in apparent continuation of an anticline in the Kinnikinic quartzite northeast of Pass Lake. Evidently pressures were high, for the complex mass of dolomite and argillaceous rocks near Pass Lake and along the same zone farther north is locally schistose. None of the other rocks in the part of the Lost River Range within the Borah Peak quadrangle shows equivalent evidence of compression. The quartzite of the overthrust block in and near the head of the cirque that contains Pass Lake has been bent into highly irregular, in part recumbent, folds, some of which are broken by minor thrust faults (Fig. 4).

Between Long Lost and Dry creeks the structure suggests forces similar to those that produced the overthrusts described above. The rocks after being folded appear to have been subjected to further pressure as a result of which minor recumbent folds are plentiful, and there has been much contortion. The only actual, known overthrusts in this area are the minor ones at the crests of anticlines, but, if the pressure that distorted the major folds had continued to the point of rupture, a low-angle thrust similar to that under Borah Peak would have resulted.

The zone of thrusting in the Lost River Range is so nearly in line with the prolongation of the curved zone of the Bannock and related overthrusts in the Fort Hall Indian Reservation (Mansfield, 1929, p. 55–58) as to raise the question of possible genetic relationship. The thrusts in the Borah Peak quadrangle, although similar in several respects to the Bannock thrust, are far smaller and involve older rocks. In view of the conditions outlined in the discussion of the regional setting of the quadrangle, it seems logical to suppose that the thrusts here discussed result from

Figure 1. Outcrop about Half a Mile Southeast of Jayrock Prospect

On southwest flank of Lost River Range.

Light-colored bluff is gently inclined Kinnikinic quartzite, overthrust on intricately contorted Jefferson dolomite. Retouched to bring out structure.

Figure 2. Terraces on South Side of Grouse Creek

Below confluence with Mill Creek.

DETAILS OF AN OVERTHRUST AND OF TERRACES IN THE LOST RIVER RANGE

FIGURE 1. GENERAL VIEW OF LOST RIVER RANGE
From sec. 29, T.10N., R.22E. Highest peak shown is Borah Peak.

FIGURE 2. VIEW SOUTHWEST FROM B. M. 9750
On ridge north of Rock Springs Creek. Small part of a nearly level portion of the top of this ridge appears in foreground, and a similar ridge crest is visible in profile in background.

VIEWS IN THE LOST RIVER RANGE

somewhat earlier, premonitory shoves. Later when deformation extended eastward into the great accumulation of weak Mesozoic strata, the spectacular fractures of the Bannock zone resulted.

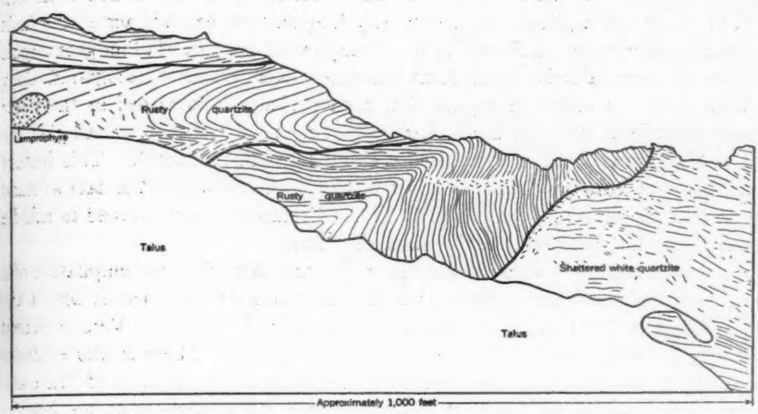

FIGURE 4.—*Section in Kinnikinic quartzite in the cirque wall above Pass Lake and northeast of the Jayrock prospect*

Shows curved thrusts in contorted beds. The drawing is based on a field sketch and photographs.

NORMAL FAULTS

Introductory note.—The quadrangle contains numerous normal faults, which are diverse in trend, in amount of displacement, and probably also in origin. Repetition of movement along old fractures and the concealment of much of the pertinent data by the abundant detritus hinder classification. For purposes of description the principal faults may be grouped into those whose average trend approximates N. 45° E., those with an average trend that varies from nearly due north to about N. 15° E., and those that strike northwest. In addition, a few strike nearly east. The first set of faults mentioned forms a major fault zone that extends transversely across the quadrangle. Those of northerly and northwesterly trends are likewise outstanding structural features, but the few of easterly trend require no further description. Where faults are sketched on Plate 1 mostly on the basis of geomorphic data, the weakness of the evidence is indicated by question marks.

Major transverse fault zone.—Most of the faults trending approximately N. 45° E. are grouped in a single major fault zone 3–5 miles wide and with a mapped length of nearly 25 miles. The zone extends from near Whiskey Springs on the southwest side of the Lost River Range to the Lemhi Range near Summit Ranch. The principal faults have their downthrow to the northwest in the Lost River Range and in the opposite direction northeast of the Pahsimeroi River. The trend and perhaps also the size of some of the valleys which, like that of Mahogany Creek, are floored by glacial and alluvial deposits may be attributed to buried faults of this zone. As the largest overthrust in the vicinity of Borah Peak is bounded at both ends by faults of the zone here described it is inferred that this zone originated during overthrusting. The inference is strengthened by the fact that the faults bounding the overthrust have sufficient horizontal shift to accord with the concept that they are tear faults. Some of the faults of the zone displace strata belonging to the Challis volcanics. In T. 11 N., R. 24 E., however, the Donkey fanglomerate extends across the fault zone and appears to be unaffected by it. Conspicuous scarps and other geomorphic evidence of comparatively recent fault movement were nowhere recognized along the fault zone. It might be argued that such evidence is furnished in the lower average altitude of the Lost River Range crest north of the fault crossing at the head of Mahogany Creek as contrasted with altitudes farther south. This feature might, however, have resulted from other factors. On the whole, the data at hand suggest that the faulting began as early as the Cretaceous, was renewed in middle Tertiary time, but has been inactive since that time.

Recent reconnaissance work by the writer in connection with the compilation of a geologic map of the State suggests that the fracture zone may persist across the Lemhi Range to the vicinity of Gilmore. Unpublished studies by Vernon Scheid show that the area close to Gilmore is complexly faulted. There is also evidence that the fault zone may continue southwestward beneath the alluvium of Thousand Springs Valley, thence up Big Lost River, and over the mountains at the head of Summit Creek to, and beyond, the valley of Big Wood River north of Ketchum. Several short faults whose trends and positions accord with such a concept are known in this area, and it has been suggested (Umpleby, Westgate, and Ross, 1930, p. 72, 73, Fig, 6, Pl. 1) that the topography along this line favors the assumption of a zone of weakness. The extensions to the northeast and southwest of the fault zone across the Borah Peak quadrangle would give it an aggregate length of nearly 90 miles and make it one of the major structural lineaments of south-central Idaho. This is in harmony with a suggestion made earlier (Ross, 1925, p. 13) that certain topographic features may reflect regional structures. The validity of this suggestion as applied to features of northeasterly trend has been strengthened by subsequent discoveries. The recognition during reconnaisance studies in 1943 of faults of this trend across the lower valley of the Pahsimeroi and along neighboring parts of the Salmon River is among the latest of these.

Faults of nearly northerly trend.—The second group of faults, those trending more nearly northerly, includes a well-marked fault of large displacement that extends up the valley of the West Fork of the Pahsimeroi and continues southwest through Leatherman Pass; a similarly long but much less well-established fault inferred to underlie Doublespring Creek and to continue southward along the front of the Lost River Range, possibly to the vicinity of Whiskey Springs; and several much shorter faults.

The large fault through Leatherman Pass would, if continued northward under the alluvium of the Pahsimeroi River, pass through the fault zone trending N. 45° E. and extend close to the west border of the Donkey Hills. Meinzer (1924, p. 8) has suggested that a fault may exist here and that the Donkey Hills may have been uplifted. He bases his inference on eastward-tilted terrace remnants along Goldburg Creek and on the probability that Pahsimeroi River once flowed through the gap between the main Donkey Hills and outlying hills to the north. Uplift may have caused diversion of the river into its present channel, leaving Goldburg Creek to occupy part of its former course. Further evidence of recent structural disturbance is furnished by the fact that Goldburg Creek near the school of the same name flows in intricate meanders through marshy land, bounded by terraces cut during former vigorous erosion. This stretch is north of that postulated by Meinzer to have been occupied formerly by Pahsimeroi River and just above a sharp deflection in the course of the creek. Uplift across the lower reaches of Goldburg Creek would tend to dam the portion of the stream near Goldburg School, with results such as those noted.

The concept that the fault through Leatherman Pass, continued northward, caused the uplift of the Donkey Hills requires that this fault be hinged in the northern part of T. 10 N., R. 23 E. An alternative explanation is that the sole influence of this fault on the topography was in the aid it gave to the processes of erosion. The uplift of the hills might be equally well ascribed to flexure or to an independent fault which may traverse the westernmost tier of sections in T. 11 N., R. 24 E., with a more nearly northerly strike than the one through Leatherman Pass. Such a structural feature might pass southward up Burnt Creek instead of the West Fork of the Pahsimeroi.

The fault through Doublespring Pass is inferred mainly from the fact that the straight, broad valleys of Willow and Doublespring creeks head against each other in a pass conspicuously lower and broader than any other that notches the Lost River Range within the quadrangle. As the lithologically monotonous and irregularly contorted Brazer limestone predominates here positive evidence of faulting is difficult to obtain. The inference is supported to some extent, however, by apparent discordance between minor lithologic and structural features on opposite sides of the two valleys. If a fault does extend through Doublespring Pass, it may continue south along the straight steep range front as far as the mouth of Vance Canyon, where the trend of the range front changes abruptly. Bedrock is entirely concealed over a wide expanse in front of this part of the range.

Faults of northwesterly trend.—The only faults of northwesterly trend definitely mapped are short. However, the forms of the Lemhi and Lost River ranges so nearly approximate those of mountains commonly interpreted as carved from fault blocks as to have led to the suggestion that the Lemhi Range is bounded by faults on the southwest (Meinzer, 1924, p. 6–9, 15, 16; Anderson, 1934, p. 19, 21; 1947, p. 67–68), and the similarly steep but more irregular southwestern front of the Lost River Range may also result from faulting. Anderson suggests that a normal fault may border this front, but his published evidence applies mainly to the part of the range south of Mackay, which has not been mapped in detail. Kirkham (1927, p. 27, 28), on theoretical grounds, suggests that the Lost River Range is bounded on both sides by thrust faults, but the studies here summarized do not substantiate this concept, at least for the Borah Peak quadrangle. The thrusts mapped on the southwest flank dip in the opposite direction from that required by Kirkham's postulate.

Along the front of the Lemhi Range the concept of late normal faulting based on topographic form received some support from geologic evidence. In and near the western part of T. 13 N., R. 24 E., a block composed of Challis volcanics and Donkey fanglomerate lies against the steep face of the Belt rocks with a remarkably straight contact about 6 miles long. The lava and associated pyroclastic beds in this block appear to lie nearly flat except as they have slumped valleyward along landslips. In one outcrop, apparently not affected by slump, lava with an inclination of 35° strikes perpendicular to the near-by contact with the Belt rocks. Meinzer (1924, p. 11, 24) notes dips of 15° to 20° E. and NE. in beds that apparently belong to the Donkey fanglomerate. These Tertiary rocks have probably been downfaulted. The inferred fault, if projected northwest beyond the limits of the Borah Peak quadrangle, would pass under the alluvium of the valley. It would be near and approximately parallel to the range front, which is so straight and has such well-facetted spur ends that some geologists would regard these topographic features as sufficient proof that the entire range is bordered by a fault. In the tungsten mining district in T. 14 N., R. 23 E., shear planes of suitable trend near the mouth of Patterson Creek (S. E. Clabaugh, personal communication) support this concept. Further, the fractures that determined the course of the principal veins in near-by mines strike N. 20°–40° W. and dip about 80° SW. (Callaghan and Lemmon, 1941, p. 9) so that they approximately parallel the range front. To the southeast, beyond Big Creek, irregularities in the attitude of the Belt strata favor the concept that fracturing has occurred approximately as indicated by the dashed line on Plate 1. No individual fault was detected here, and the shape of the mapped contact between the two Belt formations seems incompatible with any large fault displacement. Thus available evidence is in accord with the idea that the Lemhi Range from the vicinity of Big Creek northwestward is bounded by a fault or fault zone, although the geologic data do not prove this idea.

As already noted, the part of the Lost River Range front from Freighter Spring to south of Whiskey Spring may owe its straightness and steepness to a fault of northerly trend concealed beneath the alluvial fans that border Thousand Springs Valley. Obviously such a fault is not adequate either in position or in trend to exert a major influence on the northwesterly trending range as a whole. The parallel fault through Leatherman Pass shows no such effect on the shape of the range front near its point of emergence as that postulated for the supposed fault south of Freighter Spring. Thus, there is scant evidence to support the concept that the steep range front results from the combined effect of a series of faults of nearly northerly trend emerging from the mountains in echelon pattern.

No geologic evidence of normal faults alined along the Lost River Range front has been found either in the Borah Peak quadrangle or in the contiguous part of the Bayhorse region. The part of the range front that extends across the boundary between these two areas, in and near T. 11 and 12 N., R. 21 E., is conspicuously straight and facetted for a distance of about 11.5 miles, as has been shown by the writer (1938, Pl. 8A). In that report, however, the conclusion was reached that the Challis volcanics cover large areas along the range front without detectable displacement, and that the scarplike front of the range resulted largely from control of erosion by upturned bedding planes of the Paleozoic rocks in the mountain front (Ross, 1938, p. 85–87). The facets on the spur ends closely approximate dip slopes. If erosion was aided by faults, the movement along these faults would appear to have ceased prior to the eruption of the Challis volcanics. Any such faults would have been incidental to the folding in the Paleozoic rocks. Several minor faults of this character are shown in the northwestern part of Plate 1, but none near the southwestern range front.

Near Willow Creek Summit, T. 11 N., R. 21 E., continuous rock exposures bridge the gap between the Lost River Range and the hills in the Bayhorse quadrangle. If a major fault bounds the range, some trace of it should be discernible here. None was found with the exception of a somewhat doubtfully inferred minor thrust in and near sections 25 and 36, T. 11 N., R. 21 E. This has guided the erosion of Arentson Gulch and its counterpart north of the divide. The displacement is so small that this fault can have had little effect on the sculpture of the main range.

In summary, minor normal faults of northwest trend, presumably related to the folds formed during the Mesozoic era, are mapped. Major faults of similar trend, suggested by the shape of the mountain ranges, probably exist along parts of the southwestern front of the Lemhi Range but have not been proved to exist along the comparable part of the Lost River Range. As faults of this kind involve the Donkey fanglomerate (Pliocene ?), much of the movement along them must be later than the deposition of that formation.

FOLDS IN THE CHALLIS VOLCANICS

The Challis volcanics are flexed more irregularly and, on the whole, more gently than the underlying Paleozoic beds. They rest on a somewhat rough erosion surface, and in places the flows had appreciable initial dips. These facts, coupled with the difficulty in determining the attitude in outcrops of the more massive flows, hinder interpretation of the details of structure. In a general way the beds and the surface on which they rest dip away from the mountains, although there are many local exceptions to this. Some of the exceptions may result from doming of lava that originally flowed down irregular slopes. Some result from the effect of minor faults.

At the northwestern end of the Pahsimeroi Mountains the volcanics form a plunging anticline, whose northeastern flank is in the Borah Peak quadrangle. The northwestern flank is in part within the Bayhorse quadrangle (Ross, 1938, p. 84–85), and the tip must be in the unmapped area north of the northeast corner of that quadrangle.

At the head of the valley of the Pahsimeroi most of the volcanics dip away from the Lost River Range without apparent relation to the broad valley north of them or to the Donkey Hills east and northeast of them. There is a poorly defined anticline west of Burnt Creek. Farther southeast the volcanics are inclined toward the valley of Little Lost River, a fact that can be appreciated best by inspection of the foothills east of the quadrangle border. Many of these are composed of well-stratified tuffaceous beds that dip eastward and southeastward at angles of about 30°.

SUMMARY

The quadrangle shows the effects of repeated folding, associated with both thrust and normal faulting. Some of the normal faults may have suffered renewal of movement at different times. The earliest recorded folds are of northerly trend and formed in late pre-Cambrian or very early Paleozoic time. At a later stage the Paleozoic rocks were bent into closely spaced asymmetric folds, dominantly of northwesterly trend, but some, apparently slightly younger, trend more nearly west. The folds of both these sets in the Lost River Range have been arched into an anticlinorium. The crests of some of the asymmetric anticlines are broken by steep thrusts, and the Paleozoic rocks are also affected in places by more extensive thrusts of lower dip, some segments of which are bounded by tear faults; minor unsystematic wrinkles on some folds suggest late-stage deformation under light load. These various folds and faults formed in successive steps during the latter part of the Mesozoic. The Tertiary rocks have been bent, probably in the Miocene, into ill-defined folds that in general dip away from the mountains and are discordant with the more complex structures in the older rocks beneath.

Normal faults are numerous, and some are of large vertical displacement. One zone with a trend of N. 45° E. appears to constitute part of one of the major structural lineaments of this part of the State. It includes faults on which movement began during the Mesozoic deformation, but much of the fracturing along the zone took place after eruption of the Challis volcanics. The other major faults in the quadrangle fall into two groups, one of northerly, the other of northwesterly trend. Probably much of the movement in both sets took place shortly after the eruption of the Challis volcanics, but the faults may in part record renewal of disturbance at that time along old lines of weakness. Some of the faults of both sets are reflected in the present topography. These and other bits of evidence, recorded in the discussion of the physiography of the quadrangle, indicate revivals of movement in late Tertiary and perhaps also in Quaternary time.

PHYSIOGRAPHY

SALIENT FEATURES

From the geomorphic standpoint, the outstanding features of the region that includes the Borah Peak quadrangle are the long, narrow ranges flanked by alluvium-floored intermontane valleys. These ally this part of south-central Idaho with the area in the southeastern part of the State included in the Middle Rocky Mountain province of Fenneman (1930) more closely than with the Northern Rocky Mountains. Fenneman placed the region in the latter province largely because the wide expanse of the Snake River Plain effectively separates it from the mountainous parts of southeastern Idaho.

South-central Idaho has been exposed to subaerial erosion since the end of the Paleozoic. During this long interval much crustal deformation has occurred, the results of which are, in varying degree, reflected in the present topography. This control of erosion by ancient structural features is particularly evident in the part of south-central Idaho in which the Borah Peak quadrangle is situated. In areas to the northwest, where the mountain masses are broader (Ross, 1931, p. 369; 1934c, p. 103), a widespread erosion surface which began to be redissected before the start of Challis volcanism is sufficiently preserved to influence the present topography locally. After the volcanism long-continued erosion produced a surface of subdued relief, modified remnants of which are more completely preserved in the present topography.

The great local relief and attendant intricate dissection in the Borah Peak quadrangle hinder recognition of both the pre-Challis and post-Challis surfaces. Fragmentary later surfaces record a complicated erosional history as yet incompletely understood. One set of these is so distinct and widespread that it is here named the Donkey Hills surface. The diagrammatic sections in Figure 5 illustrate the relationships between these surfaces and the history of their development.

Glaciation, marked throughout south-central Idaho, has had particularly conspicuous results in the Borah Peak quadrangle, which includes the highest mountains in the State. The abundant detritus produced by this process has combined with alluvial deposits in surrounding and partially burying the mountains with highly permeable material that has had profound influence on late geomorphic developments. These deposits, coupled with climatic contrasts related to the pronounced relief, have interfered with systematic development of drainage patterns. The Salmon and the Snake, the master streams of the region, are not far away, but large parts of the intricately dissected mountains in the Borah Peak quadrangle are not connected with either by continuous stream channels.

OLD EROSION SURFACES

Pre-Challis surface.—Present outcrops of the Challis volcanics in the Borah Peak quadrangle are so scattered that they give scanty information as to the surface on which they were deposited. In neighboring regions (Ross, 1934b, p. 83–86; 1938, p. 87–91) that surface appears to have been worn down extensively, but to have been uplifted and youthfully dissected, at least in some localities, before being covered by the volcanics. In the Borah Peak quadrangle the Challis volcanics locally reach altitudes close to 10,500 feet, but it is doubtful if the formation ever covered the highest peaks. Much of the volcanic rock that remains uneroded is low on the slopes. In several localities, such as Spring Hill Mountain, the Challis volcanics rest in steep, irregular, depositional contact against the older rocks as a result of the rejuvenation of erosion shortly before volcanism began. In Figure 5 the surface on which the volcanic rocks rest is represented as having been dissected during the rejuvenation. Original relationships have been modified by structural disturbances and by extensive erosion since volcanism ceased. When Challis volcanism began hills occupied approximately the positions of the present mountains.

Post-Challis surface.—The erosion surface formed over wide expanses in south-central Idaho after Challis volcanism ceased is so marred in the Borah Peak quadrangle by later sculpturing as to be recognizable with difficulty. In areas described by the writer (1934; 1938) the post-Challis surface had reached or passed maturity before its development was halted by renewed dissection. Where the flatter parts of it remain comparatively undisturbed they are conspicuous among the present mountains. In a few places in the Bayhorse region the post-Challis surface has been so little modified that patches of residual soil remain. In areas farther northwest, as yet studied only in reconnaissance fashion, upland areas preserve patches of reddened and weathered material thought to be of similar origin. Some of these are on ridge tops rendered narrow by glacial and fluviatile sculpture. Such facts suggest that, even where greatly dissected, the residual patches of the ancient erosion surface may have been little lowered or modified by weathering and erosion.

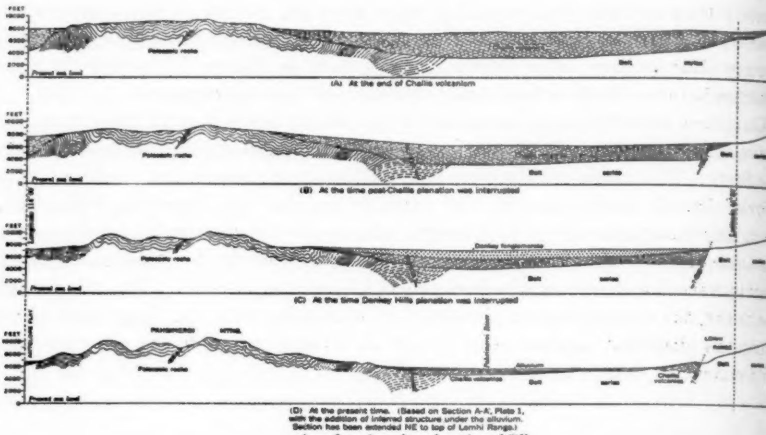

FIGURE 5.—*Sections to illustrate steps in the geomorphic development of the Borah Peak quadrangle*

The remnants of much of the flatter part of the post-Challis surface in the Bayhorse region stand at altitudes near 9000 feet, and some monadnocks are about 2000 feet higher (Ross, 1938, p. 91). In the Borah Peak quadrangle, especially in the Lost River Mountains, the average present height of possible remnants is greater, and the dissection much more intricate. There has thus been exceptional opportunity for modification in the appearance of the post-Challis surface by glaciation and other processes so that a casual observer would see little to suggest the former presence of a surface of low relief over the present mountain mass. For example in the area of Figure 1 of Plate 8, the irregular topography and lack of accordance of summits are the most conspicuous features. Closer studies impress the observer with the discordance between many of the ridge tops that wind eastward from the range crest and the precipitous valley sides and jagged peaks around them. By contrast, large parts of the ridge tops appear nearly flat. Indeed portions of them are so gently inclined that an automobile might be driven across them without the construction of a road. The topographic map is so generalized that it fails to show the character of these ridges. The profiles in Plate 1 indicate that in a zone 5 to 8 miles wide the ridge tops have only minor relief. Few of the comparatively level tops much exceed a quarter of a mile in width, but the break between them and the valley walls on either side is even more abrupt than would be inferred from the contour map. One particularly noticeable ridge top is just south of Massacre Mountain in the southeastern part of the quadrangle. It is along the trail that leads east up Hell Canyon from Long Lost Creek and is surmounted by a knoll on which is a bench mark whose altitude is 10,550 feet. The ridges near and southwest of Grouse Creek Mountain furnish other examples of subdued ridge-crest topography that are much more impressive when viewed in the field than they are on the map. The sections in Figure 5 are in this area. Figure 2 of Plate 8 shows in the foreground a portion of the ridge crest between Dead Cat and Rock Spring canyons, and, on the skyline, the even-crested ridge southwest of Rock Spring Canyon. This view was taken at an altitude of 9750 feet above sea level, which is not far from the average altitude of the comparatively level ridge tops east of the range crest in this part of the quadrangle. The flatter portions of these ridge tops have a pavement of loose blocks such as that visible in the foreground of Figure 2 of Plate 8, with local stretches of bare rock. The ridge south of Massacre Mountain, which is broader than those near Rock Springs Canyon, is largely bare. The backbone of the Lost River Range is very narrow and serrate. Portions between the peaks in the Pahsimeroi Mountains average somewhat less than 10,500 feet in altitude, and from Borah Peak southward their average altitude is nearly 1000 feet higher.

In the small part of the Lemhi Range within the quadrangle parts of the ground along the crest between altitudes of 9500 and 10,500 feet are rolling, with some stretches that seem level in comparison to the peaks that rise above them. One such area that is more conspicuous in the field than on the map is in and near sec. 1, T. 13 N., R. 24 E. Presumably if topographic maps of the northern part of the Lemhi Range were available other examples could be cited, as the study of this region first led Umpleby to advocate the hypothesis that traces of a high-level erosion surface remain in Idaho (Umpleby, 1912, p. 139–147; 1913, p. 22–29).

In both ranges the uplands interpreted as remnants of the post-Challis surface are now at altitudes 1000 feet or more above most such features in other parts of Idaho. They are throughout more than 9500 feet above sea level and rise locally to fully 11,000 feet above sea level with monadnocks that culminate in Borah Peak (12,655 feet) (Pl. 8, fig. 1). Planimeter measurements indicate that the monadnocks now constitute about 5 per cent of the area of the quadrangle. Crustal disturbances and the vicissitudes of erosion have increased the relief in the fragmentary remains of the old surface and modified even those portions that seem comparatively well preserved. In the Casto quadrangle (Ross, 1934b, p. 85), where much of the post-Challis surface lies at altitudes of 8500 to 9000 feet, ridges of soft tuff at altitudes close to 8000 feet were interpreted as parts of the same surface lowered by differential weathering. In the Borah Peak quadrangle the rocks of the uplands are all sufficiently resistant so that this kind of differential lowering is less effective. Similarly the rate of modification of old erosion surfaces by creep proposed by Capps (1941, p. 25–32) for the placer mining districts of west-central Idaho is not directly applicable to the conditions in the Borah Peak quadrangle. His idea that the surface was lowered at a rate of 6 feet in 30,000 years is based on observations of unconsolidated morainal material in an area which he describes as mature with no surviving "broad, flat remnants of the old erosion surface." The areas in the Borah Peak quadrangle regarded as modified remnants of the post-Challis erosion surface are not so broad as similar remnants farther west but are equally discordant with the slopes of the modern valleys. Capps' statement that the ridges in the region he described "all have continuous slopes from ridge crest to adjacent valleys" would not apply to the ridges here discussed. Although intricate dissection has made them narrow they are otherwise more comparable to the plateau-like areas, on which he agrees that creep would be ineffective, than to the mature slopes in the area he describes. One factor in the preservation of a semblance of original form in the narrow remnants in the Borah Peak quadrangle is that they are, and apparently have long been, near and above timber line. Much of the precipitation falls during the winter, and even during the summer storms it is largely frozen so that erosion as a result of runoff is slight. Creep unquestionably takes place, but, in the flatter and wider parts of the ridge crests, is slight. Conditions existing in these uplands resemble those in parts of the Sierra Nevada where Matthes (1930, p. 38–40) concluded that changes since late Miocene time have been so slight that the present upland topography "is in a general way still representative of that which was evolved before the land acquired its present altitude" except that dissection has gone so far that few remnant ridge tops exceed half a mile in width. They differ markedly from those topographic features in Pennsylvania which led Ashley (1935, p. 1395–1436) to conclude that lowering of ancient surfaces has been so rapid as to cause him to suggest drastic revision of the age assignment of the Schooley peneplain. The folded limestone that underlies most of the ridge crests in the Lost River Range is probably less resistant to erosion than the exceptionally hard granitic rocks that underlie surfaces described by Matthes. This is in part counterbalanced by the greater solubility of the limestone which permits escape by seepage of part of the water that might otherwise erode the ridge tops. The conclusion that seems to fit the facts best is that those upland surfaces in the Borah Peak quadrangle that have sufficient width to be clearly discordant with the steep slopes that border them represent fragments of the post-Challis surface modified by removal of all the original soil but with the rock surfaces once clothed by that soil not profoundly changed either in form or in relative position. No direct measure of the lowering of the present ridge tops with reference to the original surface is at hand, but it probably does not exceed a few hundred feet in those places where the post-Challis surface has not been destroyed by valley cutting by streams and glaciers. Monadnocks such as Borah Peak (Pl. 8, fig. 1), the narrow backbone of the Lost River Range between peaks (Pl. 2, fig. 1), and similarly narrow lateral ridges, such as that shown in Figure 2 of Plate 8 have been so sculptured by erosion as to lose all resemblance to the forms existing in post-Challis time. Parts of them have been greatly and irregularly lowered. The crustal disturbances since that time have, of course, affected the attitudes and mutual relationships of the fragments of the post-Challis surface.

LATER EROSION SURFACES

Here as in the Bayhorse region (Ross, 1938, p. 91–93) the topography contains an incomplete record of a complicated sequence of geomorphic events in late Tertiary time not yet completely understood. This record includes fragments of old erosion surfaces or berms (Bascom, 1931, p. 172–173) represented by nearly level ridge and mountain tops and high-level benches, more or less independent of modern mountain gorges. These berms do, however, tend to border the older and larger depressions such as Pahsimeroi Valley, which originated in Tertiary time, prior to the present intricate dissection of the mountains.

Bermlike surfaces can be discerned at different places throughout the mountains at altitudes ranging from over 9500 feet above the sea to little over 7000 feet along the borders of the intermontane valleys. They thus grade either into the lower, reduced remnants of the post-Challis surface or into modern stream terraces and pediments. Each individual berm is separated from any near-by berms of different dates by slopes markedly steeper than any within the berm itself. As these different remnants are fragments of surfaces formed at intervals throughout a time interval equivalent to most of the Tertiary period, it is improbable that all of the surfaces had the same origin. Some may well have been pediments; others may not. Available data are inadequate for the consideration of such details.

One set of these erosion remnants is sufficiently well preserved to warrant brief discussion. Berms which range in altitude from a little higher than 8500 feet to somewhat more than 7500 feet above the sea are so similar in their relations to each other and to the post-Challis surface above, and the valley floors below, as to suggest that they originally formed parts of a single rolling erosion surface which may be called the Donkey Hills surface as some of its best-preserved remnants cap parts of these hills. This surface, exclusive of monadnocks, had a relief, within the quadrangle, of 1000 feet or less. If it be assumed that all parts of the quadrangle now at or below the level of erosion remnants of supposed Donkey Hills age were brought to low levels during the Donkey Hills planation, about 30 per cent of the quadrangle rose as monadnocks above the surface thus produced, and the maximum relief at the culmination of Donkey Hills erosion probably exceeded 3000 feet. Hence, Donkey Hills planation was interrupted at a distinctly earlier stage in the erosion cycle than that attained by post-Challis planation, which left a much smaller proportion of monadnocks. (*Compare* sections in Figure 5.)

Small but distinct berms correlated with the Donkey Hills surface are rather closely spaced along the flanks of each of the major components of the Lemhi Range within the quadrangle, mostly at altitudes between 8000 and 8500 feet. They are especially conspicuous south of the South Fork of Big Creek. Extensive remnants cap the greater part of the Donkey Hills, with a few summits rising above them. The northeastern flank of the Lost River Range contains numerous others, such as Mahogany Hill, Spring Hill Mountain, and the ridge south of Dry Creek Reservoir. Several of these remnants have monadnocks rising as much as 500 feet above them (Pl. 9). At the north end of the range Wino Basin and such contiguous surfaces as the terrace at the 8500-foot contour on the north side of Grouse Creek are correlated with the Donkey Hills surface. On the southwest flank of the range remnants of this surface are smaller and less conspicuous. They include the tops of the buttresses mentioned in the description of the topography of the quadrangle, one of which is shown in Figure 1 of Plate 2. The broad areas that crown the hills on both sides of Willow Creek Summit are likewise correlated with the Donkey Hills surface.

The Donkey Hills surface is underlain by rocks that differ widely in lithology and structure, ranging all the way from quartzite of Belt age to poorly cemented fanglomerate. The fanglomerate is especially well displayed in some parts of the Donkey Hills. Similar material, however, underlies benches interpreted as remnants of the Donkey Hills surface in such places as the south side of the valley of the Big Creek in the northeast corner of the quadrangle and, less definitely, east of Willow Creek. Hence, the Donkey Hills surface reached its culmination after the intermontane valleys and some, at least, of the major valleys within the mountains had been deeply eroded and floored by alluvium to depths greater than remain in most present valleys.

The effects of differences in resistance displayed by the different rocks are evident in the details of remnants of the Donkey Hills and similar surfaces. A number of the larger remnants of this kind are underlain either by argillaceous rocks or by basaltic (Pl. 9, fig. 1) and similar lavas. These rocks soften and tend to weather into small fragments. An area underlain by such rock long exposed to weathering would yield readily to planation with the result that short-lived episodes of planation would leave more distinct records here than in more resistant rocks. The same factors could tend to make such areas form low parts of any single erosion surface. In interstream areas erosion remnants on such rock would tend to preserve their low relief while being lowered in altitude by subsequent erosion. The broad expanses of berms correlated with the Donkey Hills surface that are carved on quartzite emphasize the relative importance of that surface as contrasted with scattered berms at miscellaneous altitudes which record short, local episodes.

The isolated erosion remnant east of Wino Basin and over 1000 feet above it shows a somewhat exceptional relation to rock character. This surface is carved on soft, gently inclined argillaceous rocks in process of emergence from beneath a cover of more resistant limestone. Thus, in this instance, structural form had as much to do with the flatness of the surface as the effects of lateral planation.

Bermlike surfaces below the remnants of the post-Challis surface, and formed both earlier and later than the Donkey Hills surface, are widely scattered over the quadrangle. Some of these may perhaps be more closely related to one of the two named surfaces than can be realized from available data, but most of them doubtless represent minor steps in the intermittent progress of erosion. At least one step probably intervened between the post-Challis and Donkey Hills episodes, and one or more periods of incipient planation took place between the Donkey Hills cycle and the time when present streamways were filled with glacial ice. In the latter interval the floors of Pahsimeroi and Thousand Springs valleys were lowered from several hundred to over 1000 feet, mainly by removal of much of the alluvium (Donkey fanglomerate) dumped into them prior to Donkey Hills planation. At the same time the mountain valleys that had been filled with similar alluvium were largely cleared out.

REGIONAL DRAINAGE CHANGES

The present intermontane valleys of this part of Idaho correspond in approximate position to depressions that were first formed prior to Challis volcanism. Since then there have been various changes in the drainage pattern of the region. The

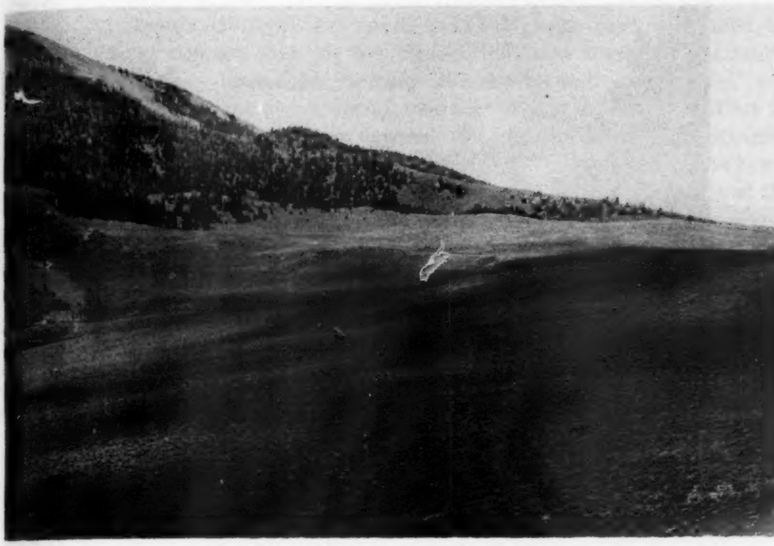

FIGURE 1. DONKEY HILLS SURFACE

On divide at head of Wino Basin. Surface floored with gravel which overlies basalt belonging to the Challis volcanics, and Paleozoic beds, mainly Brazer limestone. Border of Grouse Creek Lake visible at left edge of view.

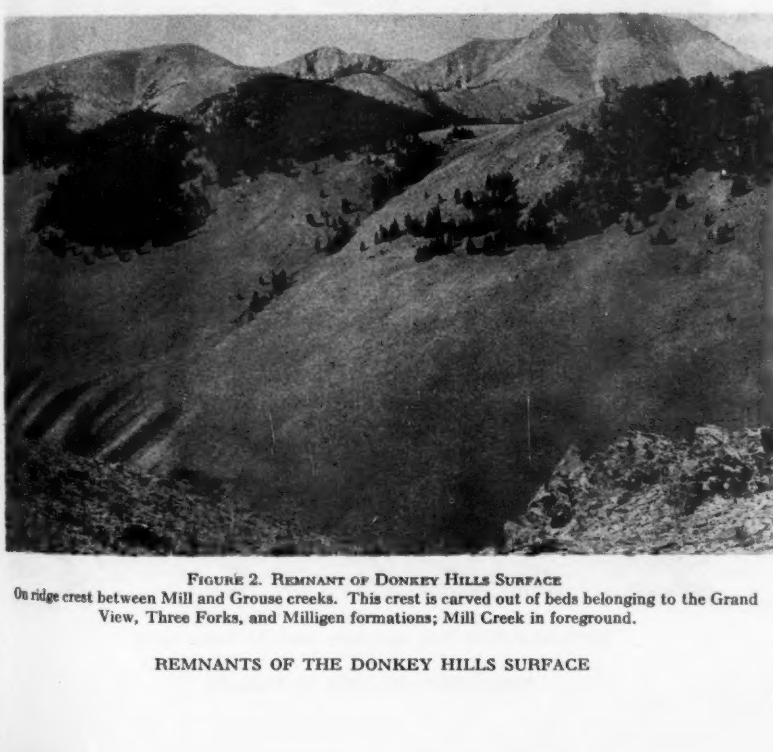

FIGURE 2. REMNANT OF DONKEY HILLS SURFACE

On ridge crest between Mill and Grouse creeks. This crest is carved out of beds belonging to the Grand View, Three Forks, and Milligen formations; Mill Creek in foreground.

REMNANTS OF THE DONKEY HILLS SURFACE

FIGURE 1. SAWMILL GULCH

Short distance out on fan beyond mountain border. Shows loose boulders that compose its left embankment. Bushes along channel of gulch indicate that no flood of destructive violence has passed recently. Sawmill Gulch is typical embanked gulch.

FIGURE 2. EMBANKED GULLY IN T.14N., R.25E

Northeast of Borah Peak quadrangle. Photo by George Crowl.

EMBANKED GULCHES OR GULLIES

different geologists (Umpleby, 1913, p. 29–30; Atwood, 1916, p. 697–732; Kirkham, 1927, p. 11; Shenon, 1928, p. 4–5; Anderson, 1947) who have speculated on this agree in the concept that the low divides that now break the continuity of the intermontane depressions between the Beaverhead and Lemhi, and the Lemhi and Lost River ranges are of comparatively recent origin. That is, each of these two long and conspicuous depressions is supposed to have been occupied originally by a single master stream. Ideas as to the direction of flow of these hypothetical streams, their date, and the part played by deformation in the origin of the valleys differ.

Final conclusions on these questions await detailed studies over a much larger area than the Borah Peak quadrangle, but clearly the present streams are not adequate to have produced the intermontane depressions. Evidently the configuration of the bedrock surface near Summit Ranch is opposed to the concept that the intermontane depression between the Lemhi and Lost River ranges was occupied by a single, through-flowing stream at any time since the late Tertiary. Those who believe that some of the valleys that are now separate were once linked by through-flowing streams call attention to the almost imperceptible divide near the southern end of T. 12 N., R. 24½ E., west of Summit Ranch. This is about 400 feet lower in altitude than any similar divide within the quadrangle and is wide and nearly flat. However, quartzite is exposed across almost the whole width of the valley at the lower end of the reservoir at the Summit Ranch, and from here to the divide the valley floor is covered by open water and swamp land. This is in part because of the reservoir dam, but it is doubtful if water could be held so well if permeable alluvium underlay the valley here to any great depth. This evidence that the divide is underlain by bedrock at slight depth implies that no through-flowing stream has crossed it since the depressions now filled with alluvium were carved along the present valleys of the Pahsimeroi and Little Lost rivers. The fault that crosses the valley east of Summit Ranch (Pl. 1) has probably been inactive so long that it has little bearing on the drainage problem. Thus the divide near Summit Ranch differs only a little from the more obvious one at Willow Creek summit on the west side of the Lost River Range. Both of the two principal forks of the Pahsimeroi River head in unsurveyed T. 9 N., R. 23 E., and Little Lost River heads in a wide valley floored with Challis volcanics and material resembling the Donkey fanglomerate near the southeast corner of T. 13 N., R. 25 E., east of the Borah Peak quadrangle. These localities are far from any of the conspicuously low divides that have aroused speculation as to former drainage patterns. Presumably Umpleby had these facts in mind when he stated: "The Little Lost and Pahsimeroi valleys seem to have been developed by streams that flowed in opposite directions and occupied channels whose upper ends were nearly parallel and only a few miles apart" (Umpleby, 1917, p. 20). It is not clear how this statement is to be reconciled with his earlier idea that the valley of the Pahsimeroi was formed by a southward-flowing stream (Umpleby, 1913, p. 30).

The conclusion that seems best to accord with present information is that, if the Pahsimeroi-Little Lost River intermontane depression was once occupied by a single through-flowing stream, the continuity of the channel was broken either when the Donkey Hills erosion cycle was interrupted or earlier. Since Donkey Hills time erosion has obliterated so many of the details of the earlier topography that speculation as to the direction of flow in the hypothetical through-flowing stream is not warranted by data available within the Borah Peak quadrangle. Although the hills along the divide at Willow Creek summit are conspicuous in contrast to the nearly flat divide near Summit Ranch, the similarity suggests a like history of development of the topography of the two areas. That is, if the valleys of the Pahsimeroi and of Little Lost River were once joined as a single river valley, the same may be true of the two great depressions on either side of Willow Creek summit southwest of the Lost River Range.

GLACIATION

The effects of sculpture by mountain glaciers are evident throughout the higher parts of both the Lost River and Lemhi ranges. Most valleys that extend to altitudes above 8000 feet head in cirques whose stepped floors commonly hold small lakes. Figure 1 of Plate 5 illustrates the stepped character of many of the cirques, but in the valley shown talus is so plentiful that no lake exists. The cliffs, pinnacles, and narrow ridges that characterize the highest parts of the Lost River Range result from glacial carving, modified in detail by the later effects of frost and other weathering agents.

Below the cirques the valleys have been rendered U-shaped by the passage of glaciers for different distances downstream. Such evidence of the former presence of glaciers rarely extends lower than 7500 feet above sea level and in many of the smaller valleys is unrecognizable below 8000 feet. That is, few of the glaciers had a maximum extent of over 4 miles, and many were less than half that length. One of the largest glaciers was in the valley of Dry Creek, where the effects of glacial erosion are evident as far downstream as sec. 11, T., 9 N., R. 24 E., and gravel deposits of possible glacial origin extend nearly to the junction with Long Lost Creek. Apparently none spread beyond the limits of the stream valleys in which they originated.

In most the larger glaciated valleys deposits left by the glaciers retain their characteristic forms. The hummocks of unconsolidated material at the summit of Doublesprings Pass appear to have been dumped there by ice and to have been almost unaffected by later erosion. Lateral moraines are well preserved along the lower reaches of Christian Gulch, and smaller ones remain along Dry Creek and other streams. Kettle and kame topography is especially well displayed along the upper valley of Mahogany Creek in and near unsurveyed sec. 30, T., 10 N., R. 23 E. The wide, generally dry valley floor here forms a bench devoid of stream channels, a fact that would not be inferred from the contours on Plate 1.

Most of the glacial deposits that have retained their characteristic forms belong to a single period of glaciation, probably of Wisconsin age. No effects of the earlier glacial advance known to have occurred in neighboring areas have been recognized, although it is improbable that mountains as lofty as the Lost River Range could have escaped the earlier activity. Possibly part of the unconsolidated material of doubtful origin (*see* section on Donkey fanglomerate) was deposited during the earlier glacial activity.

No glaciers remain, but in several localities, such as the cirques surrounding Borah Peak and Pass Lake near the head of the West Fork of the Pahsimeroi, snow banks persist throughout the year. Some of these have blue ice in their interiors. Possibly the ice masses are remnants of small glaciers that existed here during what has been called "the little ice age" (Matthes, 1939, p. 518, 523; 1940, p. 396–406; 1941, p. 1008–1009; 1942b, p. 376–378; 1942a, p. 204–215) of a few thousand years ago.

TERRACES

Most of the longer stream channels throughout the Borah Peak quadrangle are bordered along certain stretches by one or more sets of terraces. Parts of terraces are cut on hard rock, but most of them are carved on more or less imperfectly consolidated alluvial material. Plate 1 shows each of the terraces sufficiently distinct and persistent to be depicted on such a map. There are, of course, many fragmentary terraces that are not shown. For example, Meinzer (1924, p. 8; Fig. 3) describes three prominent terraces where the Big Creek in the northeast corner of the quadrangle emerges from the Lemhi Range. Similarly, while the generalized character of Plate 1 permits only one set of terraces to be shown near the junction of Grouse and Mill creeks, Figure 2 of Plate 7 shows at least three at this locality. In several places terraces were formerly present but have been so obscured by slumping that they are not mapped. The gravel slopes south of Long Lost Creek near its mouth afford good examples of this.

In general, terraces prominent enough to be mapped on Plate 1 are confined to the upper slopes of the alluvial fans that border the mountains and to contiguous parts of the larger stream valleys within the mountains. Pahsimeroi and Big Lost rivers, the two master streams within the quadrangle, have discontinuous and, on the whole, ill-defined terraces in the intermontane valleys, but, except at the head of Pahsimeroi Valley, none of the terraces of tributary streams persist as far as the river channels in the center of the valleys. It is striking that subparallel, terrace-bordered channels are closely spaced in many localities. The channels of Dead Cat Canyon and neighboring gorges and those east of Carlson Ranch afford examples visible on Plate 1. Similar, but more complicated features are displayed in other localities, notably the part of Pahsimeroi Valley in and near the eastern half of T. 11 N., R. 23 E. Here conspicuous subparallel channels bordered by bluffs cut in alluvium to depths ranging up to 50 feet nearly coincide with the boundaries of the valley fill on both sides of Pahsimeroi Valley. Between these bounding channels the valley is traversed diagonally by several streamways bordered in different places by from one to six terraces.

Features such as those above outlined appear to record incisions resulting from sporadic discharge of flood water from the mountains rather than steps in a normal erosion cycle. Generally the material cut into to form the terraces is sufficiently poorly consolidated to yield readily to the erosive effects of the flood waters. However, it is sufficiently permeable so that as the waters spent their force and began to spread out on the alluvial fans of comparatively low gradient they were readily absorbed. Under present conditions stream runoff is greatest when the snow melts in the spring. Some cutting is annually done at this time, and probably the smaller and fresher terraces cut in alluvium have this origin. Incisions made by modern, minor floods of this character shift in response to a number of variable factors so that it seems unlikely that the deeper terrace-walled streamways have been cut by this means alone. The channels bordered by successive sets of terraces at different heights, especially, would appear to have originated when the stream flow was greater than it now is. When glaciers occupied the mountain valleys, especially when the last of them were melting and disappearing, conditions may well have been more favorable than at present for the trenching of the alluvium of the valley borders. Then, as now, conditions fluctuated, and the different streamways were undoubtedly initiated and deepened at different times. Hence, no two terraces would be expected to be exactly synchronous. The marked differences in depth and in the sequence of the bordering terraces in the different streamways accord with this. The discontinuous and irregular pattern of the channels and terraces in the part of Pahsimeroi Valley between Spring Hill Mountain and the Donkey Hills as shown on Plate 1 illustrates the erratic fashion in which cutting must have been done. Similar irregular channelling on scales too small to be depicted on Plate 1 is common in the region.

The explanation above offered for the trenches and terraces that are conspicuous features of the upper parts of the alluvial slopes in both Pahsimeroi and Thousand Springs valleys agrees approximately with that proposed by Meinzer (1924, p. 6-9). He concluded "that the erosion of the upper parts of the alluvial slopes was due to climatic changes rather than to earth movements". Meinzer distinguishes sharply between the features just described and the rock-cut terraces along the steep front of the Lemhi Range which he attributes to the effects of faulting and uplift. As trenching is still intermittently in progress on the upper alluvial slopes, or bajadas, Meinzer's suggestion of climatic change should be modified to include seasonal fluctuations.

MODERN CONDITIONS

The high, narrow mountain ranges with relatively abundant precipitation, flanked by semiarid depressions whose alluvial fill reaches far up into the principal mountain valleys, furnish marked contrasts in conditions of erosion at the present time. Within the mountains the glacial and alluvial fill of the larger valleys and probably also loss of some water to underground channels in the limestone result in fewer perennial streams than would be expected from an annual precipitation estimated to exceed 30 inches. Nevertheless erosion is vigorous, especially in the spring, when the streams are swollen by water from the abundant melting snow. Wherever the steeply graded mountain valleys emerge at the borders of the intermontane depressions, down-cutting ceases abruptly. The thick fans that girdle the mountains are almost static under present conditions. In the drainage basins tributary to Big and Little Lost rivers very few of the mountain streams within the quadrangle maintain channels continuously across the bajadas, and rarely does the runoff from the mountains remain at the surface long enough to reach these two rivers, either by the numerous distributary rivulets, the gashes in the alluvium cut during violent storms, or through the agency of the rare sheet floods. In the area tributary to the Salmon River the isolation is less complete, but even here no perennial streams from mountains within the quadrangle reach the Salmon, and few mountain streams maintain channels far across the alluvium in the intermontane valleys. Irrigation canals, which tap the larger streams close to the mountain borders, supplement natural agencies in eliminating surface water supply to the Pahsimeroi and other master streams. The extreme permeability of the fill in Pahsimeroi Valley constitutes one of the principal obstacles to agriculture there (Meinzer, 1924, p. 21–23).

Throughout the quadrangle the discontinuous channels across the alluvium of the valley borders shown in somewhat conventionalized fashion on Plate 1 were cut mainly when more water was available than at present. Most of them are lined and choked with bushes and trees and show little evidence of having been actively extended recently (Pl. 2, fig. 2; Pl. 10, fig. 1). Most of the valleys and gullies that reach the mountain borders have discontinuous depressions in the fans which aid in the discharge of flood waters, but these are shallow and inconspicuous. They form a braided pattern on the fan slopes, rendered visible by the arrangement of the surface layers of gravel and of the vegetation with respect to them. Most such minor depressions end upslope in a shallow enlargement or basin which represents the final effort of the last flood to extend the depression headward.

The interference with the normal process of valley deepening through headward erosion provided by the barrier of permeable and difficultly eroded alluvium between the master streams in the intermontane valleys and their mountain tributaries serves to emphasize certain features. Among these are channels formed largely through the force of debris-laden water pushing from above down the slope rather than the ordinary process of sapping that proceeds from below upstream. The channels formed by pushing have banks composed of debris that rise above the level of the surroundings. It is proposed that features of this character be called "embanked gullies" or gulches, according to whether they are small or large. Similar features are common throughout the mountainous parts of the western United States, but large embanked gulches which show all gradations with the channels of ordinary ephemeral streams require special conditions such as are well exemplified on the steeper, southwestern flanks of the mountain ranges here described. Differences in detail are numerous, depending on the slope, the character of the material transported, the resistance to erosion of the material traversed in forming the gully or gulch, and other factors. The essential requirements are that water on a steep slope is concentrated in a small cross section and has an abundance of loose, largely coarse detritus with which to work. The channels are either created or deepened by the pushing action of the moving detritus and may be further deepened by ordinary processes of headward erosion either in the late stages of runoff after the water is no longer overloaded or by water without excessive load flowing at some subsequent time. The banks are composed of unassorted fragments, brought down from above or gouged from the channel, shoved and flung to either side by the powerful, heavily loaded stream of water in the channel. Most of the material thus displaced is concentrated in narrow embankments at the channel borders, but scattered boulders may extend some distance to either side. Figure 6 is a diagrammatic cross section of an embanked gully or small gulch. In the drawing the fragments are rounded as they might be in a stream channel or alluvial cone. The smaller gullies are commonly on talus slopes where the material would be more angular. In the cross section shown many of the fragments that compose the embankments are represented as larger and somewhat less rounded

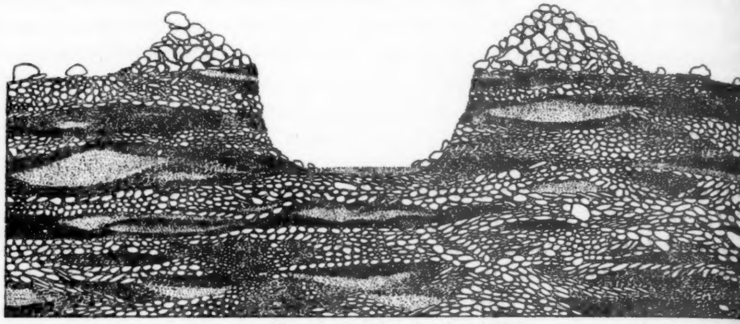

FIG. 6.—*Ideal cross section through an embanked gully*

than the average of those in the mass that has been cut into. This is a common but possibly not essential feature. Figure 1 of Plate 10 shows an embanked gulch somewhat larger than that sketched in Figure 6, and Figure 2 of Plate 10 shows a smaller one. Figure 2 of Plate 10 shows a gully that crosses ground so resistant that very little channel incision was possible. This view was taken in a part of the Lemhi Range beyond the limits of the Borah Peak quadrangle. At the lower ends of the gullies or gulches deltalike masses of boulders in crescentic ridges, concave upstream, are built up wherever sufficient detritus has been carried this far. These masses resemble the transverse ridges on talus rivers (Ross, 1938, p. 98–99) and the mounded fans described by Mackin (1941, p. 80). At the ends of the larger embanked gullies, especially, they have been modified or obliterated either in the late stages of the storm that formed them or in later storms.

Embanked gulches which constitute integral parts of the regional drainage system are particularly well displayed in the upper parts of the fans in T. 8–9 N., R. 22 E. Sawmill Gulch (Pl. 10, fig. 1) is in this area. Here the process has been aided by the abundant poorly consolidated debris that mantles the lower slopes of the mountains as shown in Plate 1 and, in more detail, in Figure 2. Most of the stretch of Sawmill Gulch shown in the latter map is not embanked, but the part of Vance Canyon in T. 8 N., R. 22 E., has embankments.

In the few published descriptions of features similar to the embanked gulches and gullies of the Borah Peak quadrangle the embankments rather than the channels have been emphasized. Matthes' (1930, p. 108–109) description of "torrent channels" is an exception to this. Torrent channels may be regarded as a special kind of embanked gullies or gulches. Embankments similar to those here discussed have been called levees, with the addition of qualifying terms to express differences in origin. As Matthes notes in his description of torrent channels, they are, however, so different genetically from the well-known natural levees formed by deposition during overflow of streams that it seems wise to avoid the term "levee" in connection with them. The embankments of the Borah Peak quadrangle resemble some of the mudflow levees described by Sharp (1942, p. 222–227) and by Fryxell and Horberg (1943, p. 457–472). In the development of embanked gullies and gulches, however, moving aside of material and the cutting of channels are dominant as contrasted to the movement downslope of masses of detritus as in the instances described from Wyoming. This difference is recognized in Sharp's suggestion that the features described by Matthes might be called torrent levees.

GEOLOGIC HISTORY

The Lemhi and Swauger quartzites are considered to be representatives of the great mass of sedimentary rocks, widespread in Montana and Idaho, known as the Belt series. These rocks in general are believed to have been laid down in extremely shallow seas in basins that reached southward from the Arctic regions into Montana and Idaho (Deiss, 1935, p. 104–106; Fenton and Fenton, 1937, p. 1873–1970). Those parts of the series which contain notable amounts of detrital feldspar grains are thought to have been derived from arid lands composed largely of crystalline rocks. These interpretations of conditions governing deposition appear to hold for the Lemhi and Swauger quartzites even though neither has been correlated with any of the recognized Belt formations. The coarser and more imperfectly rounded grains that make up much of the quartzite in the Swauger record more powerful currents than those that deposited the Lemhi beds, and the fact that locally shale, conglomerate, and calcareous rocks appear to be included in the Swauger suggests fluctuation in conditions of deposition. Probably such features reflect rejuvenation caused by incipient crustal disturbances that culminated in the unconformity at the top of the Swauger quartzite. The movements that caused the unconformity, in this locality, were not, however, sufficient to produce any profound modification of erosive conditions, for the shallow, shifting seas of pre-Cambrian time appear to have persisted into the early Paleozoic. These movements interrupted sedimentation and caused shifts in the sources of material, but the exceptionally pure quartzite that composes most of the Kinnikinic beds must have been derived from a land that had long been subjected to weathering and erosion. Apparently the disturbances that affected the Belt rocks at or soon after the close of pre-Cambrian time left parts of the old land masses undisturbed at least as late as the Ordovician. Late in that period conditions changed so that calcareous deposits were laid down within what is now the Borah Peak quadrangle. At this time organic life flourished to a greater extent than had heretofore been possible in this locality. The sea was somewhat deeper, and the neighboring land had probably assumed a more diversified character than it had when quartz was almost the sole material that it contributed to the deposits of the Kinnikinic sea. During the latter part of the Ordovician and the Silurian and Devonian periods the area was covered by marine waters much of the time, although there were several interruptions in deposition. Most of the deposits were calcareous and are now somewhat magnesian, but land was probably at no time very far to the west. Quartz sands mingled with the calcareous deposits rather frequently.

Fluctuations of different kinds took place throughout the Paleozoic. Some of the formations are so thick as to show that subsidence was persistent, but the seas were narrow and currents in them shifted. From Kinnikinic time through the Devonian the deposits of the Borah Peak area were so similar to those of southeastern Idaho (Mansfield, 1927, p. 48–59; 1929, p. 14–22) as to imply that they were laid down in the same seas, even though conditions of deposition were not always identical.

Sedimentation in neighboring parts of Montana during this period was similar (Winchell, 1914, p. 23, 27, 28; Emmons and Calkins, 1913, p. 49–73; Shenon, 1931, p. 46–48). This implies that the marine basins were elongated in a northwesterly direction, roughly parallel to the present major folds. The Grand View dolomite, first recognized in the eastern part of the Bayhorse quadrangle and well developed throughout the Lost River Range, apparently has no counterpart either in southeastern Idaho or in near-by Montana. It records a marine invasion that seems to have been local.

In the late Devonian, and to a much greater extent during the early Mississippian, argillaceous deposits became abundant. Fragments of plants mingled with these deposits during Milligen time, which suggests that a land covered with vegetation was not far off. The Milligen formation is somewhat thinner in the Borah Peak quadrangle than it is farther west and is not known either in western Montana or in southeastern Idaho. Evidently the conditions of sedimentation that permitted the accumulation of large amounts of fine-grained material rich in carbonaceous matter did not persist into those regions.

The Brazer limestone, with its abundant remains of corals and other organisms, is the principal product of Carboniferous activity preserved in the Borah Peak quadrangle. It shows that following the deposition of muds during Milligen time clearer seas spread over this region, although similar muds may have been laid down farther west contemporaneously with part of the Brazer limestone (Ross, 1934a, p. 976–977; 1938, p. 29–33).

Apparently marine invasion of this area ceased at or soon after the end of Brazer deposition. The relative uplift that began at this time culminated in major folding during the latter part of the Mesozoic era. Here, as in other parts of south-central Idaho, the deformation was a long-continued process (Ross, 1936, p. 376–383). It undoubtedly began long before the Idaho batholith reached its present position and continued during emplacement, consolidation, and the adjustments that followed. The anticlines and synclines so conspicuous in the Lost River Range formed early in this sequence of events. As pressure continued they were overturned and broken by minor thrusts along the anticlinal axes. The anticlinorium into which the whole mass of Paleozoic rocks in the range has been arched is similar to the compound anticline in the Wood River region (Umpleby, Westgate, and Ross, 1930, p. 68–70) which is regarded as superimposed on the already tightly folded rocks as another step in the deformation related to igneous activity. The thrusts related to folds in the Borah Peak quadrangle are broadly similar to the thrusts of the Wood River region. In the latter region certain faults on the borders of igneous masses have been inferred to be thrusts tilted to high angles as a result of intrusion. This implies that the original thrusting preceded invasion of magma into the part of the crust now exposed to erosion. In the Borah Peak quadrangle the early folds were bent and in places were broken by thrusts that were flatter and, on the whole, of greater displacement than those along anticlinal axes. Exactly comparable features do not appear to exist in the Wood River region, but the strikes of these comparatively late structures are nearly parallel to the compound anticline in that region which bends to the northwest in conformity to the larger sinuosities in the eastern contact of the Idaho batholith. The bends in the folds close to the batholith are thought to be related to the intrusion of the latter, and it has been pointed out that, in general, folds in the Lost River, Lemhi, and Beaverhead ranges farther away do not so closely parallel the batholithic contact (Ross, 1936, p. 376–381). The late bends and thrusts in the Lost River Range, while inadequate to control major trends, may well be correlated in time and genesis with the bends superimposed on the old folds near the batholith as a result of pressure exerted during the emplacement of the magma. Thus, even though the Lost River Range is 50 miles east of the exposed part of the Idaho batholith, intrusion of that great mass may have affected its structure markedly. If the marked curves in the thrust planes result from folding, they may record deformation later than the intrusion of the batholith.

The small but widespread intrusions of dioritic and lamprophyric rock in the Borah Peak quadrangle are presumably offshoots of larger igneous masses still deeply buried. Whether these are satellites of the Idaho batholith or somewhat younger intrusions that result from eastward migration of intrusive igneous activity (Ross, 1936, p. 382) cannot be determined from the evidence within the present area. Presumably the small deposits that contain lead, zinc, and other metals, widely distributed in the quadrangle, came in mostly as a result of this igneous activity.

When the protracted period of uplift and deformation related to the Idaho batholith ended, the region must have been well above sea level and subject to erosion. As the anticlinorium in the Lost River Range corresponds approximately in trend and position with the present mountains and may have been one of the later results of the deformation, it seems probable that elevations existed on the site of the Lost River Range at the close of the Mesozoic era. Apparently ancestors of this and of the Lemhi Range were present at the time of Challis volcanism, rather early in the Tertiary period. Flows and ash deposits spread widely over the region but may not have completely covered the mountains. They did, however, reach, at least locally, to altitudes within about 2000 feet of the present summit of Borah Peak so that the topography at the close of the volcanism must have been much more subdued than it now is. Since then erosion has continued in a series of steps, interrupted by several rejuvenations. The mountains have been intricately carved, in part by ice, and the valleys have received more sediment than their streams could remove. This alternate uplift and reduction by erosion is still in progress.

MINERAL DEPOSITS

SUMMARY NOTE

Prospect holes are widely scattered over the quadrangle, but at the time of study there were no operating mines, and the production had been trivial. Deposits containing lead, zinc, and some copper, with small amounts of gold and silver are known, but apparently all are small and discontinuous. Quartz veins with specularite are plentiful in the Lemhi Range but are without known commercial value. The principal prospects are those at the mouth of the canyon of Big Creek, in the Lemhi Range, the scattered openings for lead and zinc in the Lost River Range between Willow and Rock creeks, near Lone Cedar Creek, and above Pass Lake near Leatherman Pass. Each of these is briefly described below. There are also a number of minor prospects in Carboniferous rocks, mostly near the east border of the quadrangle.

PROSPECTS NEAR BIG CREEK

There are several cuts and short tunnels on the slope on the north side of Big Creek in secs. 21 and 22, T. 13 N., R. 24 E. They follow stringers and veinlets in the small quartz diorite mass here exposed and in schistose Lemhi quartzite near the contact. These veinlets consist of tetrahedrite, specular hematite, chalcopyrite, and their oxidation products in a quartz gangue. Some of the sulphides are disseminated in the quartz diorite near the veins.

The Swauger quartzite southeast of this locality is cut in numerous places by irregular, short lenses of coarse, milky quartz containing foils of specular hematite. Prospect pits have been sunk on some of these, but, so far as known, nothing of commercial interest has been found. A few similar veins with hematite crop out in quartzite near Sawmill Gulch in the Lost River Range. Some of the prospect pits in the latter locality were apparently intended to explore small exposures of lamprophyre sprinkled with biotite flakes with metallic sheen. Such rock has no known economic value.

PROSPECTS EAST OF WILLOW CREEK

There are numerous prospect pits and some short tunnels in the eastern part of T. 10 N., R. 22 E., between Willow and Rock creeks. No work was in progress here in 1935 or 1936, but small shipments of lead and zinc ore may have been made in the past. In the prospect in this vicinity shown on Plate 1 a slickensided slip that strikes N. 25° W. and dips 60° SW. in Grand View dolomite has been followed a short distance. Some galena occurs in fractured and silicified dolomite nearby.

PROSPECTS NEAR LONE CEDAR CREEK

On the northwest side of Lone Cedar Creek near its mouth there is a caved prospect tunnel with a rather large dump which consists entirely of dark dolomite with a few calcite stringers. About 2 miles upstream in and near a gulch not adequately shown by the contours on Plate 1 there are a number of cuts which explore fractures, in part lined with vein quartz, in the Grand View dolomite. One of the more conspicuous veins here strikes N. 25° W. and dips steeply northeast. There are other stringers of more nearly northerly trend. The vein minerals include quartz, calcite, barite, galena, and a variety of sphalerite commonly called ruby jack because of its color.

THE JAYROCK PROSPECT

The Jayrock prospect is in a saddle on the crest of the Lost River Range at the head of the cirque in which Pass Lake lies. According to a notice on the claim, it was located July 21, 1934, by L. V. Carothers. It is opened by a short bench about 3 feet deep which follows a mineralized zone that strikes N. 20° E., dips 70° NW., and seems to be about 10 feet wide. The zone is on the contact between rusty, pitted quartzite and dark dolomite and contains vein quartz and abundant limonite. The dark dolomite cannot be traced far because of the abundant talus on both sides of the ridge crest. As it is in a zone of contorted and overthrust beds it might belong either to the Jefferson dolomite or to some much older unit. There are several other places, both in this vicinity and in other parts of the quadrangle, where dolomitic beds associated with the Kinnikinic quartzite contain conspicuous amounts of limonite.

OTHER PROSPECTS

In addition to those mentioned above, there are a number of other prospects in scattered localities in the quadrangle (Pl. 1). One is in the valley of Wet Creek in the southeast corner of the quadrangle. Another is in sec. 19, T. 9 N., R. 25 E., and there is a small prospect hole in sec. 29, T. 11 N., R. 25 E. There are several openings along the valley of Grouse Creek. Most of these prospects are in the Carboniferous rocks, and the others are in the Three Forks limestone. All show irregular fractures in limestone or limey shale which are in part lined with calcite, limonitic material, and some quartz.

COMPARISONS AND SUGGESTIONS

In spite of rather thorough prospecting, development so far has resulted in no discoveries of much commercial interest within this quadrangle. This is in keeping with the fact that little evidence of igneous activity exists. However, the known mineral deposits resemble some in surrounding areas that have proved to be valuable. Deposits of some of these varieties commonly have such inconspicuous outcrops that they might well be overlooked.

The irregular deposits in Devonian and Carboniferous rocks resemble those grouped as "irregular replacement deposits in calcareous rocks" in the Bayhorse region (Ross, 1938). Some lodes of this sort in that region have been notably productive, but all present difficulties in economic development because the ore bodies are sporadic. Small masses of lead and zinc ore of this kind are reported to have been mined in the Borah Peak quadrangle, and similar, undiscovered bodies may well exist. If found in a favorable situation, such a deposit may repay mining by an individual, but a large enough mass for company operation is hardly to be expected.

Lenses of coarse white vein quartz should be tested for a possible content of tungsten, regardless of the metallic minerals visible on casual inspection. The iron in these lenses is without value, and it is doubtful if copper, lead, or the precious metals will be found in them in sufficient quantity to justify development for these metals alone, except perhaps by individuals. Tungsten minerals are, however, rather inconspicuous, and the large production obtained in recent years from the Ima mine on Patterson Creek (Callaghan and Lemmon, 1941, p. 1–21) in the Lemhi Range just north of the northern boundary of the quadrangle lends interest to the possibility that similar deposits may yet be found in the surrounding region.

Rusty, silicified beds in dolomite, especially if associated with Kinnikinic or older quartzite, might well repay assay. Most such beds are undoubtedly too low in valuable metals to be of any interest, but it would be difficult to recognize a valuable deposit of this kind without careful sampling and testing. There is considerable general similarity between undeveloped deposits in this quadrangle and those which have a long production record in the Dome district, Butte County (Ross, 1933b). Incidentally, it may be well to recall Umpleby's (1917, p. 117) reference to the fact that veins of smithsonite ($ZnCo_3$) may not always be recognized. Veins of this and kindred minerals exist both in the Dome district and in other areas in this part of Idaho such as the Warm Springs district, Blaine County (Umpleby, Westgate, and Ross, 1930, p. 195–196). As they may crop out some distance from other evidences of mineralization and look like light-colored limestone they may escape notice. They are distinguished by the fact that they are much heavier than limestone and commonly have botryoidal and drusy surfaces.

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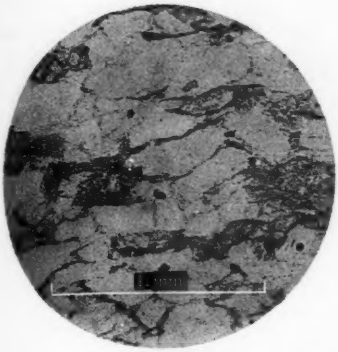
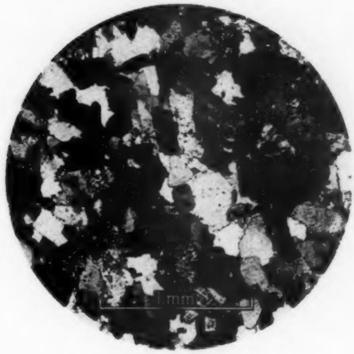


FIGURE 1



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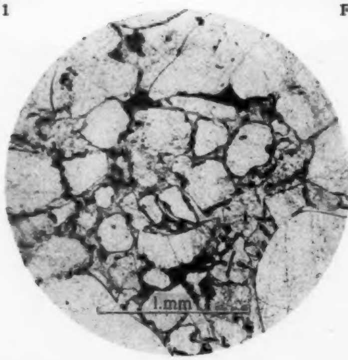

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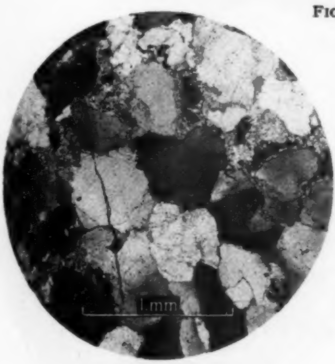

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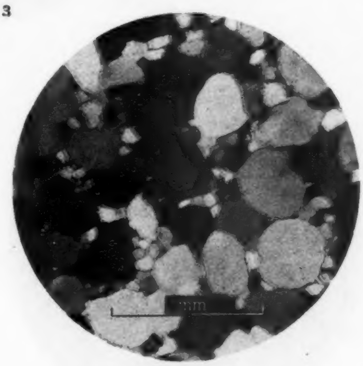


FIGURE 5

1. Lemhi quartzite from North Fork of Big Creek, Lemhi Range, plane light.
2. Swauger quartzite from head of South Fork of Big Creek, crossed nicols. Feldspar, mostly sodic plagioclase, distinguishable by twinning lamellae. Some quartz grains show parallel lines of inclusions.
3. Dark-purple quartzite from near Sawmill Gulch, plane light.
4. White quartzite from crest of detached hill near middle of eastern part of sec. 1, T.8N., R.22E.
5. Kinnikinic quartzite from Donkey Hills, crossed nicols.

Photos by K. E. Lohman.

PHOTOMICROGRAPHS OF OLD QUARTZITES

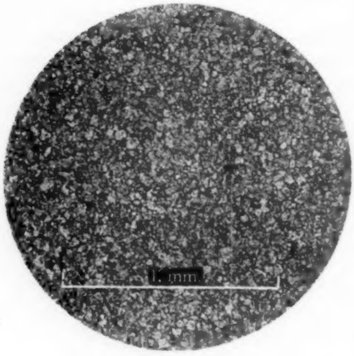
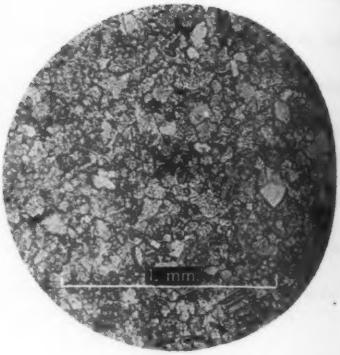


FIGURE 1



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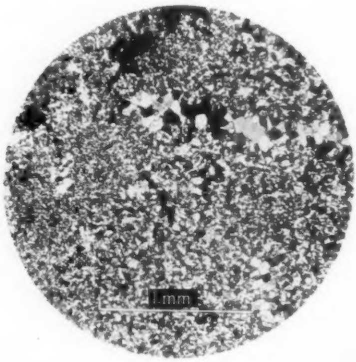
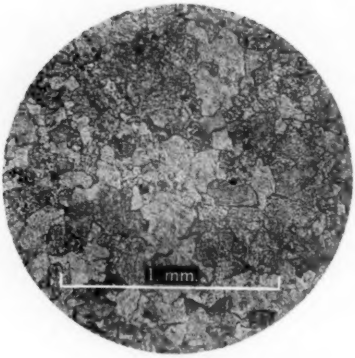


FIGURE 3



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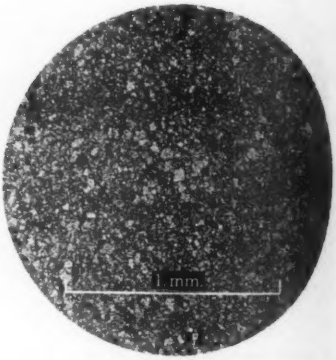

FIGURE 5

1. Saturday Mountain dolomite from small butte in sec. 36, T.13N., R.22E., plane light.
2. Laketown dolomite from unsurveyed section 28, T.13N., R.22E., plane light.
3. Quartzite in Laketown dolomite from Donkey Hills, crossed nicols.
4. Dark Jefferson dolomite from west side of Borah Peak, plane light.
5. Light Jefferson dolomite from same locality as Fig. 4, plane light.

Photos by K. E. Lohman.

PHOTOMICROGRAPHS OF DOLOMITE AND ASSOCIATED QUARTZITE

FIGURE 1

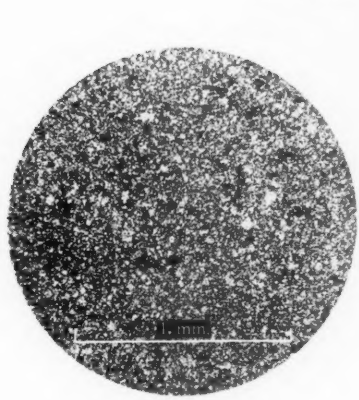

FIGURE 2

FIGURE 3

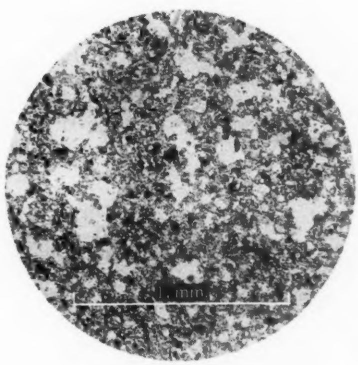

FIGURE 4

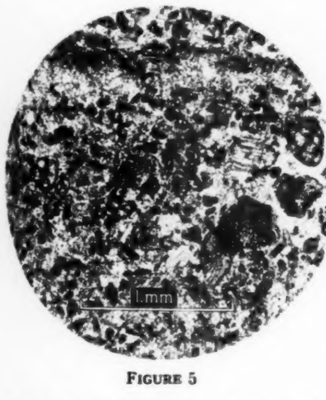

FIGURE 5

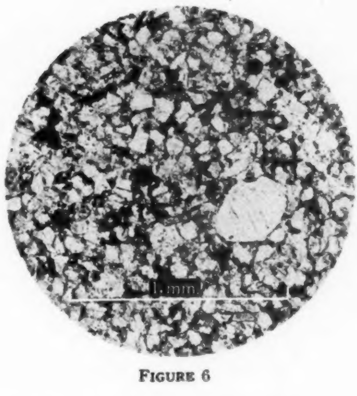

FIGURE 6

1. Quartzite in Jefferson dolomite from Donkey Hills, plane light. Photo by K. E. Lohman.

2. Grand View dolomite from Mill Creek near confluence with Grouse Creek, plane light. Photo by K. E. Lohman.

3. Somewhat coarse Milligen shale from between Mill Creek and Dry Canyon, plane light. Photo by N. W. Shupe.

4. Quartzitic rock from basal member of the Brazer limestone on upper Dry Creek, plane light. Photo by N. W. Shupe.

5. Brazer limestone on upper Dry Creek, plane light. Photo by N. W. Shupe.

6. Quartzite from Brazer limestone near Doublesprings Pass, plane light. Photo by N. W. Shupe.

PHOTOMICROGRAPHS OF DEVONIAN AND MISSISSIPPIAN ROCKS

Bulletin
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The Geological Society of America

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CONTENTS

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ABSTRACTS OF PAPERS PRESENTED AT THE DECEMBER MEETING IN OTTAWA, DECEMBER 29-31, 1947

UNIQUE ASSOCIATION OF THALLIUM AND RUBIDIUM IN MINERALS

L. H. AHRENS

Massachusetts Inst. of Technology, Cambridge, Mass.

Spectrochemical analyses of various minerals have shown that "alkali metal" thallium and rubidium are found only in potassium minerals and the cesium mineral pollucite, and that in these minerals the Tl:Rb association is very close. Altogether 167 specimens have been analyzed quantitatively, the selection comprising lepidolite, amazonite, hydrothermal pegmatitic microcline, primary pegmatitic microcline, zinnwaldite, biotite, muscovite, phlogopite, pollucite, rhodizite, and cesium beryl. The mean weight ratio $\%Rb_2O/\%Tl_2O$ was determined as 100, and the vast majority of the ratios fall within the limits of 35–300: the extreme limits are 10 and 650. A plot of log $\%Rb_2O$ vs. log $\%Tl_2O$ produced a curve of unit slope over the thousand fold range of concentration that could be investigated. There appears thus to be no shift in the ratio Rb/Tl throughout the selective crystallization of minerals, and the ratio seems to be independent of the type of host mineral. The ratio does, however, vary to some extent from area to area, and it seems likely that the cause for this variation is a chemical one. The reasons for the close association of "alkali metal" thallium and rubidium are that the radii of their ions are identical and that in certain pertinent respects their chemical properties are very similar.

With the possible exception of the pair Zr:Hf, which elements are very closely associated in minerals, "alkali metal" thallium and rubidium are perhaps the most closely associated pair of elements in the earth's crust, and their association is made more unique because thallium is a Group 3b element, whereas rubidium is an alkali metal (Group 1a).

The abundance of thallium in the earth's crust has been estimated as 0.0003% Tl, by weight.

WEATHERING OF PLAGIOCLASE FELDSPARS TO BAUXITE*

VICTOR T. ALLEN

Institute of Geophysical Technology, Saint Louis University, Saint Louis, Missouri

In Oregon plagioclase feldspars weathered to kaolinite-halloysite or to beidellite-nontronite; then, gibbsite and bauxite formed from these clay minerals by the removal of silica. Contrary statements in four recent publications subordinate this two-stage process: "that calcium feldspar gives free aluminum hydroxide", "that gibbsite precedes kaolin in the weathering of all but the most silicic igneous rocks", "that under tropical conditions laterite is developed from basic igneous rocks and clay from granitic rocks", and "that kaolinite is an insoluble hydrated silicate and the change ends with its formation".

A hole drilled by Alcoa into one Oregon ferruginous bauxite deposit indicates that weathering penetrated downward more than 175 feet with alumina, iron, titanium, and water increasing progressively but not regularly at the expense of silica. Alumina ranges from 47–25 per cent in the upper 50 feet to 35–24 in the underlying 100 feet, ferric oxide from 49–18 per cent to 32–15, titania from 8–3 per cent to 7–3, water from 25–13 per cent to 13–9; silica increases from 2–23 per cent to 21–26. A transitional layer of clay over 100 feet thick separates the bauxite at the top of the profile of weathering from the underlying parent basaltic materials of Miocene age. Irregularities within the weath-

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ered zone reflect original differences in chemical composition. Detrital sands and basaltic lava with a glassy groundmass that weathered easily to nontronite provided zones of increased permeability and susceptibility to alteration. Differentiation of the basaltic lavas caused notable differences in the original silica and titania of certain horizons.

ROLE OF THE IDAHO BATHOLITH DURING THE LARAMIDE OROGENY

ALFRED L. ANDERSON
Cornell University, Ithaca, New York

As the Idaho batholith was emplaced just before the beginning of the Laramide orogeny, it formed a part of the hinterland on the west side of the Rocky Mountain geosyncline. Acting as a strong, rigid mass, it transmitted the orogenic stresses into the thick succession of relatively weak sediments in the bordering trough, where the strata were forced into long regular folds of the Appalachian type and broken by great low-angle thrusts.

Structural studies in scattered mining districts within as well as outside the borders of the batholith show that, in transmitting the stresses, the batholith was not only locally deformed but also controlled deformation of the bordering formations. In many places the batholith was broken by minor low-angle thrusts of west-northwest trend and southwest (exceptionally northeast) dip. The granitic mass was also broken by many extensive transverse strike-slip faults trending east-northeast, apparently in response to horizontal shearing. The batholith influenced deformation of the thick Belt series for scores of miles to the north, where during late stages of crustal shortening transverse zones of faulting of general east to southeast trend were formed.

These transverse zones of structural weakness both within and outside the batholith facilitated and localized igneous intrusion and mineralization at the close of the orogeny. They also influenced deformation, igneous activity, and mineralization during a mid-Tertiary disturbance. Therefore, fracturing of the batholith and adjacent rocks during the Laramide orogeny prepared the setting for most of the ore deposits of Idaho.

TUNGSTEN MINERALIZATION AT THE IMA MINE, BLUE WING DISTRICT, LEMHI COUNTY, IDAHO

ALFRED L. ANDERSON
Cornell University, Ithaca, New York

The Ima mine, one of the leading producers of tungsten in the United States, is of exceptional interest because of (1) the many different minerals contained in its ore, (2) the zonal arrangement of the minerals about a mass of granite exposed in underground workings, and (3) the close relationship between the mineralization and the formation of the granite.

The mineralization is confined to a complex group of fractures along the crest of an anticlinal fold of quartzitic strata belonging to the Belt series (pre-Cambrian) near a small irregular mass of early Tertiary (?) granite. The fractures hold quartz veins; some near the granite are relatively large. Although composed mainly of quartz, the veins also contain orthoclase, fluorite, muscovite, sericite, rhodochrosite, siderite, and other carbonates. Orthoclase, muscovite, and fluorite occur near the granite, and rhodochrosite and sericite generally are more distant therefrom. The metal-bearing minerals are molybdenite, pyrite, sphalerite, tetrahedrite, chalcopyrite, galena, gratonite, scheelite, and huebnerite; tetrahedrite and pyrite are most abundant. The scheelite and molybdenite occur in and near the granite. The others have a less restricted distribution, the huebnerite least of all. The huebnerite appears to be one of the youngest minerals. Microscopic features of the granite suggest that it formed at least in part by "granitization" of quartzite and that its formation may represent the initial stage of the mineralizing process.

ORIGIN OF THE LIBYAN OASIS-BASINS

ROBERT VANVLECK ANDERSON

School of Mineral Sciences, Stanford University, Calif.

The 20 or more oasis-basins of Egypt and Cyrenaica cover some 35,000 square kilometers and represent excavation, below the lowest points on their rims, of several thousand cubic kilometers out of the desert plateau. The strata are subhorizontal, hard and soft, dominantly calcareous. The lowest basin attains 134 meters below sea level. A significant characteristic is the presence of water—warm artesian flows, salt marshes, lakes; and the water-bearing Nubian sandstone underlies most of the region.

In contrast with the downfaulted and geosynclinal Red Sea trough and the erosional Nile Valley the basins are neither structural depressions nor stream-erosion features. They are generally ascribed to deflation by wind. This paper presents the theory that the fundamental factor is confined ground water fluctuating in pressure level under the influence of vertical oscillations (relative to sea level) of northeastern Africa. Local hydration, solution, and collapse resulted; the wind removed products of decay, aided by some removal by underground drainage.

The inferred history is: (1) Mio-Pliocene upheaval, cutting of Nile gorge to 438 meters below present sea level, sapping of Nile walls by effluent ground water, initiation of hollows in plateau; (2) Pliocene downward shift, deposition of 568+ meters of marine Pliocene in the Nile fiord up to 130+ meters above present sea level, rise of artesian pressure level, emergence of springs at points in plateau favored by faults, and undermining of beds around such points, (3) late Pliocene-Pleistocene upward shift exposing upper part of marine Pliocene, decline of pressure level to below that of today, desiccation of debris in basins and intensified deflation down to near water level; (4) late Quaternary minor oscillations, culminating in small downward shift and rise of hydrostatic head above lowest points of floors.

PINCHI LAKE MERCURY BELT

J. E. ARMSTRONG

Geological Survey of Canada, Ottawa, Canada

Pinchi Lake and Bralorne Takla mercury mines, Canada's only producing mercury mines during the past war, occur within the Pinchi Lake mercury belt. From 1940 to 1944 the Pinchi Lake mercury mine produced more than 4,000,000 pounds of mercury valued at more than $10,000,000. The Bralorne Takla mercury mine produced 130,000 pounds of mercury in 9 months of operation. The Pinchi Lake mercury belt lies along a major fault zone approximately 150 miles long and from 200 to 1000 feet wide. The two producing mines are 90 miles apart. The ore bodies at these two mines and numerous smaller mercury deposits occur along or near the fault zone in sheared and brecciated limestone or in carbonatized serpentine. It is apparent that the fault zone provided abundant channelways for mineralizing solutions, and that deposition occurred wherever other conditions were favorable. In many places relatively impervious caprock and fault gouge have acted as traps to rising solutions and have induced local concentrations of cinnabar. At the Pinchi Lake mercury mine the larger cinnabar bodies are in limestone overlain by schist. Although trapping is undoubtedly an important factor in localizing ore, the relative permeability of the solution channels is of equal or greater importance. Cinnabar is the only mineral of importance.

GLACIATION IN NORTH-CENTRAL BRITISH COLUMBIA

J. E. ARMSTRONG AND H. W. TIPPER

Geological Survey of Canada, Ottawa, Ontario

As a result of extensive observations made during geological mapping and study of several thousand air photographs the writers have endeavored to reconstruct the glacial history of an area in excess of 45,000 square miles in north-central British Columbia. Most of the previous workers believed that the main gathering ground of the ice forming a Cordilleran ice sheet was in north-central British Columbia between the Coast and Rocky mountains and that the ice moved outward from this center in all directions. The writers believe that the ice forming this Cordilleran ice sheet accumulated in the mountains, particularly the Coast Mountains, and that the ice moved eastward across north-central British Columbia. They describe in detail many of the glacial features of the region of which some are distinctive to Cordilleran glaciation, and others which are common to all continental glaciation. The more important of these features are the widespread development of remarkable, nearly parallel drumlins and intervening depressions or groovings; three large compound eskers; and three large glacial-lake basins characterized by white silt deposits.

THE NEW COAL AGE

GEORGE H. ASHLEY

3037 N. Front St., Harrisburg, Pa.

Until 30 years ago, coal was king in energy production. For a century coal production had doubled every 10 years. Then high prices, coal strikes, and growing oil and gas production cut energy-from-coal from over 90 per cent in 1900 to under 50 per cent in 1940.

Today coal is again in the headlines. In Russia coal miners become a favored class. Britain changes cabinet members to increase coal production. In America, coal research reaches a new high, the use of oxygen in place of air, of gas turbines, of burning coal in the ground, of using coal for making oil and gasoline and high B.T.U. gas, and many other things point to new coal age.

In the last 30 years efficiency in coal use has gained from 20 per cent in rail-passenger service to 60 per cent in electri-public utility use. But the new gas-turbine locomotive may increase locomotive efficiency by 400 per cent.

But recent studies have raised serious question as to the accepted figures for our coal reserves. These and the possibility of utilizing coal in beds too thin to mine by burning underground lead to a review of our coal reserves.

INFRA RED LIGHT FOR MINERAL DETERMINATION

RENÉ BAILLY

Washington University, Saint Louis, Mo.

Many minerals which are opaque in visible light are transparent in the infra-red. By substituting a photo-electric ocular, sensitive in the infra-red, for the ordinary eye-piece, it is possible to study their optical properties just as for nonopaque minerals. Oriented thin sections can be studied with the polarizing microscope. By means of the universal stage, the optical characters, including optic sign, birefringence, axial angle, etc., can be determined. Photography with infra-red sensitive plates is useful.

The best method for determining the refractive index generally is the prism method with normal incidence. The indices of many opaque minerals are too high to be determined with the total-reflection refractometer. An adjustable slit before the photo-cell takes the place of the cross-hair in the visual eyepiece of the goniometer's telescope. In many cases, the photo-electrical method is more precise than the visual one. The photo-electric current is very variable, according to the character of minerals. It is hardly possible to use a galvanometer without previous current amplification. The amplifier must be very sensitive and stable. The infra-red light (8000–10,000 Å) is produced by a filament bulb or metallic arc lamp with adequate filters.

The properties of following minerals have been determined: molybdenite, stibnite, bournonite, stephanite, enargite, tetrahedrite, tennantite, ferberite, wolframite, huebnerite, chromite, hematite, goethite, hauerite, thoreaulite, sphalerite. The variation of index with the chemical composition has been studied for several species. The correlation is especially good for wolframite. Curves are presented showing the dispersion of huebnerite, hematite, goethite, thoreaulite, sphalerite, calcite, up to 10,000 Å.

MADDOCK QUADRANGLE, NORTH DAKOTA*

JOHN R. BALL
University of Kansas City, Kansas City, Mo.

The Maddock quadrangle is three quadrangles west and a little south of Devils Lake, North Dakota. It shows the disorganized drainage conditions and the rolling topography of one of the Wisconsin substages of glaciation. It is drained easterly by the Sheyenne River which is not far from its source in crossing this quadrangle. The North Branch of the Sheyenne joins the main river on this quadrangle and widens the valley.

The Sheyenne River has but few tributaries on this quadrangle. One tributary from the north enters the quadrangle slightly east of a prominent moraine which continues southerly across the river and then turns abruptly east about 5 miles farther south. Near the west margin of this quadrangle, this moraine apparently has diverted the Sheyenne a few miles north and northwest of the junction with the North Branch. Possibly this is not the only modification of flow effected by the ice because an abandoned channel crosses the quadrangle parallel to the present course of the river but a few miles farther south. The abandoned channel starts eastward where the present river has been diverted northward to its junction with the North Branch. Within the moraine there is much outwash mingled with and distributed around the morainic debris of the quadrangle.

METAMORPHIC ROCKS OF THE LOWER METHOW VALLEY, WASHINGTON

JULIAN D. BARKSDALE
University of Washington, Seattle, Wash.

A series of paragneisses composed of hornblende-chlorite-epidote-albite schist, hornblende schist, biotite-hornblende-quartz-feldspar gneiss, biotite quartzite, and calcite-epidote-garnet rock was intruded by a remarkably uniform granitic rock now cataclastically metamorphosed to a distinctive biotite granite gneiss. The gneissic structure of the latter parallels that of the paragneiss near their mutual contacts. The metamorphic rocks outcrop over an area of approximately 125 square miles in the lower reaches of the Methow Valley. Migmatites that formed from the paragneisses by the intrusion of hornblende granodiorite and quartz monzonite of the Chelan batholith extend south and west from the Methow along the Columbia River to the vicinity of Lake Chelan. In contrast the granitic rocks of the Okanogan batholithic complex invade the metamorphic rocks with but minor contact effects.

EFFECTIVENESS OF GEOPHYSICAL EXPLORATIONS AT FT. RANDALL DAM, SOUTH DAKOTA

ROBERT E. BARNETT
Ohio River Division Laboratories, Cincinnati 27, Ohio

Seismic and electrical-resistivity methods of subsurface explorations were made at Ft. Randall Dam, South Dakota, as a test to determine the applicability of each method to engineering investigations of flood-control projects along the Missouri River. Ft. Randall Dam was selected because of the variety of geologic conditions in the area and because of the abundance of drill holes against which the data might be checked.

The rocks of the area are relatively soft shales, chalk, and cemented sedimentary quartzite. The overburden is made up of alluvial sand and gravel, glacial till, and loess. Each of the above materials was investigated individually and in various combinations.

The tests gave results of varying reliability depending upon the combination of materials investigated. On the whole, the electrical-resistivity method gave little information which could be correlated with known conditions. The seismograph gave information of considerable value on depth determinations to the top of rock. The accuracy of these determinations varied with the materials being investigated.

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As a result of these tests, it is felt that the electrical-resistivity method of investigation will be of value in the area in outlining gravel deposits, and that the seismograph is of value in preliminary determinations of the depth to rock. However, engineers desiring to use either method must realize that each has its limitations, and investigations for which the instruments are not suited should not be undertaken.

DISTRIBUTION OF OXYGEN IN THE LITHOSPHERE

TOM F. W. BARTH

University of Chicago, Chicago, Ill.

Oxygen, which makes up more than 90 per cent by volume of the total lithosphere, shows the highest concentration in the outer shell. The regular decrease with depth represents an approximation to thermodynamic equilibrium. When highly oxidized surface rocks are brought down to great depths, oxygen will be squeezed out of the mineral lattices and returned to the surface. Therefore the deeper parts of our globe cannot become oxidized.

GLACIAL GEOLOGY AT STEEP ROCK LAKE, ONTARIO, AND ASSOCIATED ENGINEERING PROBLEMS

M. W. BARTLEY AND R. F. LEGGET

Lakehead Technical Institute, Port Arthur, Ontario; Division of Building Research, National Research Council, Ottawa.

Glacial erosion over a period of some 10,000 years is represented by varved clays and silts in the bed of Steep Rock Lake. This was unwatered to a depth of over 200 feet in order to gain access to high-grade iron ore. The glacial deposits vary in depth from 15 to 300 feet. Antevs (1947) has dealt with the remarkable varving thus exhibited. This paper deals with the more general glacial geology of the lake area and with the engineering problems associated with the bed deposits which had to be faced in developing the mine in the old lake bed.

Immediately south of the lake a distinct terminal moraine and typical kame topography are believed to represent one of the later glacial advances. The debris is essentially till, coarse and unsorted, but locally rude stratification of the sandy layers is noted. To the north is another terminal moraine, 200 feet high, striking across country at E.12°S., and leading to the known moraines of the Kenora region. The material contains very little clay but many boulders.

Some glacial deposits adjacent to the lake provided excellent road-building material. The large terminal moraine to the north had to be cut through in connection with the necessary river-diversion work. The main engineering works affected by the glacial deposits were, however, in the lake bed itself.

As the water level was lowered, some movements of the bed deposits developed as a normal process of readjustment. Study of these led to a detailed study of the deposits by means of deep borings. Unusually high moisture contents were discovered; many samples exhibited a thixotropic condition. This enabled excavation to proceed by sluicing. Study of the sediments continues, but some tentative conclusions are suggested.

EOCENE IN NORTH DAKOTA*

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c/o Dept. of Geology, Yale University, New Haven, Conn.; University of North Dakota, Grand Forks, N. Dakota

The presence of Eocene rocks in North Dakota has been reported for some time. Only recently, however, has fossil evidence been discovered that definitely proves the Eocene age of part of the beds

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formerly included in the Eocene. The beds that are definitely Eocene have been named the Golden Valley formation and include those beds bearing the fossil fern *Salvinia preauriculata*. The type exposure of the formation is near the town of Golden Valley for which the formation is named. The Golden Valley formation consists of fine-grained micaceous sands with minor amounts of light-colored clays and shales. These sands and shales overlie a basal sequence of hard white to dark-gray clays and, locally, lignites. The middle portion of this basal sequence is most characteristic because of its reddish-yellow mottled appearance on weathered surfaces, making the formation stand out wherever it crops out. This part of the formation has been called the "marker bed" and is extremely useful as a key bed in much of the area in western North Dakota in Mercer, Dunn, McKenzie, and Stark counties. The Golden Valley formation includes the beds formerly known as the "unnamed formation" of the Wasatch group. It overlies the Sentinel Butte shale member of the Fort Union formation, now considered by Brown and others to be of Paleocene age. It is unconformably overlain by the Oligocene White River group.

ENGINEERING IMPLICATIONS OF THE MASSENA-CORNWALL EARTHQUAKE

CHARLES P. BERKEY

Columbia University, New York, N. Y.

The area of chief disturbance of the Massena-Cornwall earthquake of September 4–5, 1944, covered precisely those portions of the St. Lawrence River and side country which would be occupied by the principal works of the St. Lawrence Waterway development as proposed by the U. S. Engineers. Immediately following this occurrence the writer had occasion to make a study of the effects of the earthquake and was asked to give particular attention to their bearing on the practical aspects of the prospective undertaking.

It was found practicable to correlate the destructive effects of the earthquake, which was of intensity 7 (Rossi-Forel scale), with the geologic formations of the region, of which there are four types—(1) postglacial unconsolidated marine silts, which showed the most destructive effects; (2) glacial outwash and stream deposits, next in disturbance; (3) glacial till and morainal deposits, with little or no damage; and (4) the rock floor of nearly flat-lying sedimentary formations, which were not sufficiently disturbed to cause damage to any local works.

It appears, therefore, that those structures which could be established on sound rock foundation, such as dams, locks, and power house, would be in no danger from an earthquake of the same intensity, and that works resting on glacial till would suffer no material damage. But structures involving loose sands and silts, particularly the marine silt deposits, would require special handling. This latter condition characterizes a considerable portion of the main canal.

GEOLOGICAL CONTRIBUTIONS FROM THE DEEP TUNNELS OF NEW YORK

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Of the several hundred miles of tunnels belonging to the city of New York, more than 150 miles may be classed as deep, wholly in rock, and ranging from a depth of 250 feet below the surface to more than 1,000 feet below sea level. These deep tunnels, which together cross and recross nearly all the geological formations in southeastern New York, have given to geologists connected with these works extraordinary opportunity to examine the varied assemblages of rocks and rock structures of this region. It has been possible not only to make more accurate cross sections and work out in more detail obscure structural features but to observe conditions that could not have been predicted from surface observations alone. Interpretation and inference have been reduced largely to fact.

Through approximately 40 years, data from these sources have been accumulating. Now that the works from which they have been gathered have been completed, it is a suitable time to summarize their contribution to geologic science. They are essentially a by-product from these engineering works, in which geology as an applied science has contributed its share to the works themselves.

Much the larger bulk of contribution has to do with petrologic, structural, and other factual detail, some of which can be successfully represented by structure sections; but light has been thrown on stratigraphic succession and correlation also, and on the behavior of invading magmas and other processes, with additions to local geologic history.

TYROLITE, HIGGINSITE, AND CORNWALLITE

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X-ray and optical studies on numerous specimens of hydrated basic copper arsenates yield the following data:

Tyrolite: orthorhombic; probable space group *Pmma*; the unit cell with $a = 10.50$, $b = 54.71$, $c = 5.59$ Å, $a:b:c = 0.1919:1:0.1022$, contains $4[Cu_9Ca_2(AsO_4)_4(OH)_{10} \cdot 10H_2O]$. Specific gravity, measured 3.27 (Hillebrand); calculated, 3.27. Optical characters: biaxial, negative, $X = b$, optic plane $\parallel$ (001). Crystals from Schwartz, Tyrol, are lathlike and elongated $\parallel a$; they contain microscopic spherical inclusions with a radiating structure. Crystals from Centennial Eureka Mine, Tintic, Utah, are elongated $\parallel c$. The unit cell dimensions, $a = 10.34$, $b = 26.9$, $c = 5.57$ Å, given by Wolfe for "trichalcite" from Turginsk, suggest probable identity of "trichalcite" with tyrolite.

Higginsite: several specimens labelled "conichalcite" and "erinite" from Utah, Nevada, and Cornwall give identical x-ray powder patterns which prove to be identical with the pattern of higginsite from Bisbee, Arizona. A crystal of "erinite" from Utah is orthorhombic with probable space group *Pnam* and unit cell, $a = 7.40$, $b = 9.26$, $c = 5.87$ Å. These elements agree well with the elements for higginsite given by Strunz (1939) and Richmond (1940).

Cornwallite: the identical x-ray powder patterns given by cornwallite from Cornwall and several specimens of "erinite" from Utah indicate probable isomorphous relationship of this mineral with pseudomalachite. The name cornwallite is retained for this mineral.

SYSTEM MgO-SiO_2-H_2O

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The system has been investigated up to 900°C and 30,000 lbs/in.^{2} Four-phase, P-T curves have been determined showing equilibrium relations between the vapor (or fluid) phase and the crystalline phases serpentine, talc, forsterite, enstatite, and silica. No liquid phase has been encountered, a fact that is suggestive in connection with the problem of the existence of "serpentine magma" in the pressure-temperature range investigated.

CRYPTOZOON SP., AN ORDOVICIAN ALGAE FROM SOUTHEASTERN TENNESSEE

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A large number of moundlike algal bioherms have been uncovered by quarrying operations in a limestone quarry at the Chattanooga Airport, Hamilton County, Tennessee. Similar bioherms, although less well exposed, are present 5.5 miles airline farther west in the city of Chattanooga at approximately the same stratigraphic horizon. The algal horizon occurs about 100 feet stratigraphically above the top of the Newala limestone in what has been called the Murfreesboro limestone.

At the airport quarry the bioherms are circular to elliptical in plan and are as large as 7 feet in diameter and 14 inches high. The mounds are located at random over a single bedding plane.

Each mound is composed of thin calcareous laminae, convex upward, interlaminated with crystalline calcite and calcareous oölites.

Superficially this *Cryptozoon* resembles *C. minnesotense* from the Lower Ordovician of Minnesota, but the Tennessee form attains a larger size.

FRACTURE PATTERNS IN ROCKS

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Much of the literature on the interpretation of the patterns of joints and faults is unconvincing because the principles used are either too little understood or not recognized as valid. Confidence in the validity of the principles comes from finding out that they work when applied to materials deformed in the laboratory or to rock masses undergoing observable and measurable deformation in landslides, glaciers, and the shelf ice of the Antarctic.

The following principles will be discussed and illustrated:

(1) "Plastic" deformation and fracturing are not mutually exclusive, but go on generally simultaneously.

(2) All granular or polycrystalline solids fracture either at right angles to the direction of greatest elongation or obliquely to it, forming an angle of approximately 60° with it. "Oblique shears" never intersect at right angles.

(3) The typical angle of shear appears even when lines of en echelon tension fractures take the place of the conjugate shear planes.

(4) The initial strain that produced a fracture pattern undergoes subsequent changes as deformation progresses, generally in quite unexpected ways. For an understanding of faults, the distinction of "initial" axes of strain and those developed in the course of "subsequent deformation" is basic.

(5) The fracture pattern and its relation to the axes of strain is the same from microscopic fractures in rock to hundreds of square miles of the shelf ice of the Bay of Whales region. The principles that apply to that range can safely be applied to the still greater dimensions of the earth's crust.

ROLE OF TEMPERATURE IN MINERALOGY

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Temperature endows a mineral with energy beyond that of its static crystal structure. This excess energy is the cause of many well-known mineralogical relationships, which can be comprehended as transformations.

Three different structural changes may occur in the transformation of one crystalline phase to another (polymorphism). High-low transformations may be called *displacive* from a structural viewpoint since they correspond with slight displacements of the atoms. Forms connected by displacive transformations always have related symmetries, the high-temperature form having the higher symmetry. Sluggish transformations may be called *reconstructive* since they correspond structurally to destruction of one structure and construction of a new structure from the same units. Gradual transitions correspond structurally with disordering of the atoms in the structure. Forms connected by gradual transition also have related symmetries. The disorder is the cause of solid solution. Falling temperature requires an ordering transition. If the crystal which must become ordered is a solid solution, it is necessary for one phase to transform into two; in other words, the transition causes unmixing. Many common minerals, for example, chalcopyrite and feldspar, have hitherto unrecognized high-temperature forms due to a disorder transition.

Another kind of transformation develops when an energy increase can disrupt *part* of the structural unit. When the character of the structure permits this, a reaction series results. Thus, Bowen's reaction series is merely a series of increasingly fragmented silicate units.

When a wave of temperature energy reaches the surface of a crystal, it is in a position to snap off surface units provided that the energy exceeds the bonding energy of the units. This temperature corresponds with the critical temperature of recrystallization, and the surface transformation provides the mechanism of metamorphism.

MULTIVARIATE ANALYSIS—A NEW ANALYTICAL TOOL FOR PALEONTOLOGY AND GEOLOGY

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The technique of multivariate analysis, which has been in use for 12 years, is brought forward as a suitable analytical procedure for a variety of geological and paleontological problems. The desirability of using the method in problems involving more than two variables is discussed. Several examples of its use in invertebrate paleontology are cited, and detailed directions for using the method are given.

STRATIGRAPHIC POSITION OF THE DETROIT RIVER LIMESTONE IN ONTARIO

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The Detroit River limestone is part of the "Monroe Beds", a term first used in Michigan by A. C. Lane in 1893. In 1895, Lane defined the "Monroe Beds" as extending from the Dundee limestone (Devonian) down to the lowest gypsiferous beds thus including all strata between the Dundee limestone and the top of the Niagaran series. Somewhat later, Lane recognized the presence in Michigan of the Sylvania sandstone named by Orton in 1888 from outcrops near Sylvania, Ohio. This he included in his "Monroe Beds". The gypsiferous beds were subsequently removed from the Monroe by Grabau, and the following detailed classification by Lane, Prosser, Sherzer, and Grabau appeared in 1908:

Upper Monroe or Detroit River series	Lucas dolomite Amherstburg dolomite Anderdon limestone Flat Rock dolomite
Disconformity	
Sylvania sandstone and dolomites	
Disconformity	
Lower Monroe or Bass Island series	Raisin River dolomite Put-in-Bay dolomite Tymochtee shale Greenfield dolomite

These rocks were considered Silurian until Williams (1919), working in Ontario showed the Sylvania sandstone and Detroit River limestone to be Devonian.

For many years workers in Ontario and elsewhere have placed the Detroit River rocks beneath the Onondaga limestone or formations thought to be its equivalent. The Dundee limestone is one of these formations. Ehlers has recently pointed out that fossils in the Dundee indicate a fauna distinct from and younger than that of the Onondaga. In the Mackinac Straits region Detroit River rocks overlie rocks enclosing a lower Onondaga fauna.

Recent work by the Canadian Geological Survey indicates that the Detroit River rocks occupy a similar stratigraphic position in Ontario—that is, they overlie the Onondaga limestone. They are in turn overlain by rocks thought to be the equivalent of the Dundee of Michigan. This is partly substantiated by subsurface work which shows that the Onondaga limestone of the Niagara peninsula retains its position at the base of the Devonian section throughout southwestern Ontario, and is nowhere underlain by older Devonian rock save the Oriskany sandstone. A study of the fauna collected from various outcrops of pre-Hamilton Devonian rocks is now under way.

TYPE SEQUENCE OF TERTIARY VOLCANIC ROCKS IN THE WESTERN PART OF THE GREAT BASIN*

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Tertiary volcanic rocks of the Paradise Range quadrangle in northwestern Nye County, Nevada, occur in two main groups separated by a marked unconformity or break. The lower group consists chiefly of hornblende-biotite andesite flows and breccias with minor rhyolite. Fragmental rocks are predominant. The lower group has been intruded by a stock of microdiorite, by rhyolitic dikes and plugs, and by andesitic dikes. Regional alteration is much more pronounced in this group than in the upper group.

The upper group consists of a thick section of rhyolite flows and minor fragmental rocks, flows midway in composition between latite and andesite, and a final very widespread blanket of basaltic andesite. Rocks of both groups have been mineralized, and all lie beneath the Esmeralda formation of late Miocene or early Pliocene age.

Comparisons and suggested correlations are made with other areas in or immediately adjacent to the Great Basin, both with reference to structural and petrographic features and to chemical composition.

ENGINEERING GEOLOGY OF FOSTER CREEK DAM SITE, COLUMBIA RIVER, WASHINGTON

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The Foster Creek Dam Site, 51 miles downstream from the Grand Coulee Dam on the Colombia River, Washington, is being studied by the Seattle District, Corps of Engineers, for the utilization of the 165 feet of head between the Coulee Dam tailwater and the Foster Creek rapids for power development.

The left bank and river bed at the site are excellent granite foundations for the dam and all appurtenant works. On the right bank 110 feet of pervious gravel rests on the nearly level bedrock floor. The gravel is overlain by 180 feet of extremely compact impervious glacial till. Seepage around the right abutment will constitute a major problem when 165 feet of head is imposed on the upstream exposure of the gravel.

Exploration of the gravel is directed toward determining how far it will be necessary to extend a cutoff wall so that seepage may be reduced to a safe minimum or eliminated.

Numerous drill holes and trenches have been completed, and a tunnel is being extended 1000 feet into the gravel at the till contact. Test pits are being excavated at various points along the tunnel. Washing and grouting tests of the gravel stratum are being conducted in the field to determine a feasible method of constructing a cutoff wall.

Original data indicated that 2600 feet of cutoff would be necessary to eliminate seepage. Exploration suggests that 500 feet of cutoff may encounter sufficiently impervious material so that seepage will be reduced to a safe minimum.

CARBONIFEROUS DEPOSITS OF SOUTHERN GOIAS AND MATO GROSSO

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Contrary to latest geologic maps, the Carboniferous (presumably Pennsylvanian) System was traced extensively in Goias and Mato Grosso during the past field season. The red Torres sandstone of the Bonito Plateau, Goias (long considered Permian or Triassic), carries glacial outwash horizons, varvites, sparse floral elements, and occupies stratigraphic position of the Itarare-Tubarao Series

* Published with the permission of the Director, Geological Survey, U. S. Department of the Interior.

(Carboniferous) of Southern Brazil. It was traced across the diamond region of Goias and Mato Grosso (where it is the chief source of stones) to the eastern flank of the Chapada. The Torres is the main formation in the headwaters of the Rio das Mortes, Araguaia-Garcas, Sao Lourenco, Taquari, and the Parana tributaries Claro and Verde in Goias. Glacial beds were encountered from the Torres of Rio Bonito to somewhat north and west of Poxoreo, and at many places southward on the Chapadao. The identity of the Torres formation and the Aquidauana formation of Mato Grosso was established, thus suggesting the coevality of the glacial beds on the Rio Apa, recently described by Almeida, with part of the Aquidauana.

Aside from its localized glacial aspects, and somewhat greater amount of coarse sediments, the Aquidauana-Torres is similar to the Corumbatai facies of the Passa Dois beds in Sao Paulo, including, near Poxoreo, coquinitic cherts and oölites similar to the famous Estrada Nova fossil beds, though systematically different.

Mesosaur-bearing Irati shale overlies the Torres-Aquidauana and is wholly typical of its southern occurrence, foetid, zoned, cherty limestone and bituminous shale. The concordantly overlying Estrada Nova is almost wholly red, and comparable with the Corumbatai facies, but with more and richer coquinites and fish beds.

The northward facies change of the Itarare-Tubarao, and its resemblance to the supra-Irati terrane in the southern states, leads to considerable paleo-climatological-geographical speculation and suggests trans-Atlantic correlations. South African Gondwana coal formations, supra-Irati in position, may be coeval with the Estrada Nova and bear the same facies relation to it as does the Aquidauana-Torres to the coal-bearing Tubarao. The great northwestward extension of glacial deposits makes geographically plausible identification of diamantiferous glacial horizons in Minas Gerais and Bahia with those in the rest of Brazil. The facieologic unity of the Estrada Nova-Itarare raises doubts as to current geologic classification.

DEVONIAN SYSTEM IN GOIAS AND MATO GROSSO, BRAZIL

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Recent reconnaissance of the Devonian in Goias and Mato Grosso, in co-operation with the Divisao de Geologia e Mineralogia of Brazil, more than doubles its area and makes stratigraphic-paleontologic revision necessary. The dissociated outcrops on the latest maps should be connected, and extend northward from the Garcas-Araguaia scarp of the block-faulted Serra Azul, across the upper Rio das Mortes, and onto the Roncador interfluve between the Xingu and Araguaia drainage.

The system comprises a thick basal sandy conglomeratic unit and upper shales and sandstones bearing a sparse fauna. The basal member is much more widely distributed, and outside of the Mato Grosso Chapada the fossiliferous beds are known only in fault-block remnants. At Aragarcas about 300 meters of the basal member is exposed; the upper 50 meters is red. Between Aragarcas and the Chapada the red facies progressively replaces the white so that in the Buriti scarp nearly the entire 200 meters is red. Red beds disappear rapidly south of the Buriti-Aragarcas line (my "Antiplanici" axis of 1942?). On the Bonito Plateau, Goias, red beds are lacking, and the upper 100 meters of the basal sandstone contains a sparse marine fauna. The overlying shales bear the Ponta Grossa fauna.

On the Chapada, the Devonian was traced longitudinally for over 500 kms.; rich faunas occur at both extremities. Near Sta. Ana da Chapada, in the north, the Morro Vermelho red beds (hitherto supposedly Mesozoic) underlie three fossil horizons. Immediately above the red beds, blue fissile shales contain a sparse *Leptocoelia* fauna (the Vogel-von Ammon fauna, 1893); intermediate sandstones lack *Leptocoelia* but carry the Mesodevonic genus *Tropidoleptus* in great abundance in an otherwise essentially Austral assemblage (Smith-Derby fauna, 1890, 1896); still higher, and forming the general plateau surface at Sta. Ana, a rich *Leptocoelia*-bearing, wholly Austral fauna reappears (Derby-Clarke fauna, 1913; Derby's original collection was lost). A rich new fauna, near the southern limit of Mato Grosso outcrop, includes Andean elements.

DU TOIT'S GEOLOGICAL COMPARISON OF SOUTH AMERICA WITH SOUTH AFRICA AFTER TWENTY YEARS

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A Portuguese translation of Du Toit's 1927 Geological Comparison of South Africa with South America has recently been completed by the writers. His 1928 presidential address before the South African Geological Society, which treats of other aspects of the same subject, has been translated in place of the paleontologic appendix of the original edition. The original texts are unaltered, except for typographic corrections, but have been rendered actual by extensive annotation and bibliography. Du Toit and Joaquin Frenguelli of Argentina have collaborated toward this end. During the translation period most of Du Toit's original Brazilian route was covered, and about 30,000 additional kilometers in Brazil alone. Pertinent results of these field studies are included in the notes.

As might be expected, the findings of 20 years require many changes. Happily, these are mainly in details. This is especially true for Brazil. The Argentine work has apparently fared less satisfactorily, judging from literature and personal communication. On the other hand, not all the Argentine refractory evidence agrees with our Brazilian observations.

With respect to the theoretical side of the work, it is manifest that much information, especially South American, is needed before the validity of Du Toit's argument *pro* Continental Drift can be properly evaluated. While many of the new data necessitate modifications, none could properly be said to condemn the hypothesis. Especially in Brazil, the sum would seem rather to support than detract. The translators and annotators have refrained from controversy, limiting ourselves chiefly to factual matters. It is our hope that we have rendered Dr. Du Toit as effective a champion of his cause in Portuguese as he is in English. Only time and more facts can settle the issue.

DEVONIAN STRATIGRAPHY AND PALEONTOLOGY OF THE STATES OF PARANA AND SAO PAULO, BRAZIL

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Three years of intensive restudy of the Devonian arc in Parana and Sao Paulo yield many new paleontologic and stratigraphic data on local correlation, zonation, and facieology, and for revised comparisons with other austral Devonian occurrences. An unusually complete section, hitherto unknown, at Lambedor, Parana, affords a regional stratigraphic key. With respect to the Parana Basin, the more salient results of our studies are: (1) discovery of a fossiliferous transition zone, up to 15 meters thick, between the usually barren Furnas sandstone (basal Devonian) and the richly fossil-bearing Ponta Grossa shale; (2) considerable augmentation of the Ponta Grossa faunal list both by new forms and new identifications; (3) establishment of both zonal and facieologic differences of regional correlative value; (4) the famous Tibaji sandstone proves to be a lens; (5) its fauna is facieologic and capable of development at almost any level in the shale sequence; whence (6) it seems ill-advised to apply member names to any of the local shale divisions, at least with respect to the Tibaji facies; (7) the "Barreiro" sandstone, which often overlies the Devonian shale in the northeastern limb of the arc, is to be identified with the Itarare series (Carboniferous) and (8) therefore cannot represent the regressional phase of the Devonian that Parana geologists are currently advocating; (9) like the Carboniferous Vila Velha sandstone of the Ponta Grossa area, with which it is probably to be correlated, the Barreiro is superficially similar to the Furnas sandstone but carries glacial erratic boulders, occasionally overlies varved deposits, and in several places cuts the Devonian disconformably; (10) moreover, some portions of the mapped extent of the "Barreiro" sandstone prove to be Furnas, *e.g.*, the Serra do Montenegro, uplifted by Trias-Jurassic faulting associated with the Parana lava extrusions.

NOVEL MUSEUM ARRANGEMENT FOR HISTORICAL GEOLOGY

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Cases proposed for the principal popular exhibit in the local museum of the Natural Science Association of The Catskills, near Catskill, New York, will form a hollow rectangle in the interior of which will be banks of storage trays easily accessible and removable for study by students, while the exterior will consist of a continuous series of alcoves with dioramas and specimens depicting in triplets the "billion-year fight" between earth and sun as "rounds"—each round consisting of uplift by earth forces followed by peneplanation by sun forces and by return of the sea with its period life, as manifested locally.

The length and compactness of the rock record in this area lends itself remarkably to such treatment. Three times of mountain foldings alternating with thick deposition are interspersed with quiet regional uplifts which prevail in the Neozoic, producing several peneplain levels ending in glaciation. The brief episode of glaciation (only 0.1% of the whole story) will be shown in detail in separate cases.

Sketches of the cases will be exhibited.

STRUCTURAL FEATURES OF THE BETHLEHEM GNEISS IN WESTERN NEW HAMPSHIRE

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The Bethlehem gneiss of the Mt. Clough pluton in western New Hampshire shows numerous major and minor structural features which reveal the sequence of events in the tectonic history of the body. The rock is generally medium-grained granodiorite composed essentially of quartz, andesine, microcline, and biotite. The body assumes the shape of a gigantic sheet at least 75 miles long and 1 to 5 miles thick. It intrudes metamorphic rocks in a remarkably conformable manner and is considered of late Devonian age.

Oriented inclusions in the gneiss and sills of gneiss in the country rock characterize the contact zone. Considerable contamination by the alumina-rich country rock is made apparent by the abundance of garnet and some sillimanite in the intrusive.

Detailed studies in the southern part of the body show many features of geological significance. Major structural features include gravity faults and broad folds and flexures.

Minor structural features are foliation; lineation; small flexures and folds; oriented inclusions and phenocrysts; augen; small shear zones; concordant and discordant pegmatites, aplites, and quartz veins; auto-intrusions as sills and dikes; closely spaced shear planes; and numerous joint sets. Lineation occurs as crinkling of foliation, elongated biotite flakes, girdled biotite, elongated quartz blebs, and intersecting shear and foliation planes.

A detailed sequence of events in the formation of the pluton is determined by study of the relative ages of these structural features. The pluton is considered syntectonic though certain features are distinctly later and are post-tectonic in age.

SOME PACIFIC SEA FLOOR FEATURES

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Aboard the USS HENDERSON and the USS CACOPAN, the writer observed the discovery by the use of a recording fathometer of many new ocean-floor features during Operation HIGHJUMP (U. S.

Navy Antarctic Development Project, 1947). A number of roughly conical seamounts, presumably of volcanic origin, were located. These seamounts are characterized by slopes which are slightly concave and which have an average declevity varying from 10° to 21°. An asymmetrical, fault-block seamount with a foredeep was discovered north of the Easter Island Swell. This escarpment, which is 2 miles in height, has a 63-degree scarp slope angle. Another large escarpment was found near Antarctica. Profiles of the Antarctic continental slope showed it to be comparatively gentle. The break-in-slope between the continental slope and the shelf occurs at a depth of 280 fathoms.

Two seamounts, West Twin Bank and Erben Bank, that are known to rise up from the deep ocean between the U. S. and Hawaii have recently been surveyed in detail by B. E. Holtsmark aboard the USS FIEBERLING. The banks, which display the form of a truncated cone, have extensive level summit areas at a depth of about 300 fathoms. This planation may have been produced by wave erosion during a relatively lower stand of sea level in the past. These banks have the appearance of extinct volcanoes; however, a sediment sample of clastic mineral grains from the top of West Twin Bank indicates derivation from a varied, but dominantly an acid, igneous terrane.

NEW PETROGRAPHIC REFRACTIVE INDEX METHOD

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With dark-field illumination, color criteria provide a new alternative to the usual methods for comparing index of crushed grains with immersion media. Since organic immersion liquids have steeper dispersion curves than inorganic solids, spectrum colors are produced from white light by refraction at interfaces of grains and liquid. With ordinary illumination, when the dispersion curves intersect in the yellow, the oblique illumination test produces colored grain borders as explained by F. E. Wright and others. Dark-field colors appear in bright contrast to a dark background, affect grains everywhere in the microscope field, and require no changing of focus.

Most microscopes can be adapted for dark-field illumination, which requires a hollow cone of light from the condenser, focused on the preparation, having a greater aperture than the objective. The field of view is dark, except where refraction and reflection in the preparation send light to the eye. When solid and liquid indices differ widely, grains appear white against a dark background. When indices differ by a few units in the second decimal place, or less, grains are yellow if higher and blue if lower in index than liquid. At equality of sodium index, ±.001, grains appear purplish blue with a scattering of deep-red borders.

The colors can be explained as a result of the Christiansen effect and the relative excitation curves of the three primary color sensations. They are due to the subtraction of the lost transmitted wave lengths from white light.

PETROGRAPHY OF SYNTHETIC REPLACEMENTS

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A petrographic study has been made of oriented specimens of uniform size and shape which have been reacted with solutions of copper salts at known conditions of temperature, pressure, and concentration and for known periods of time at standard rates of circulation.

The study suggests the desirability of modifying certain widely accepted criteria of replacement. The study further indicates that, at low pressure after only a very small amount of replacement, the replacing mineral forms a surface barrier over the mineral or rock being replaced. This surficial replacement prevents further access by the replacing solutions. Thus, at low pressures, the only mode of access of mineralizing solutions beyond the surficial replacement layer must be by further fracturing.

LATE CENOZOIC TRENCHES OF THE ROCKY MOUNTAINS

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A belt of great trenches extends from north-central Arizona northerly through central Utah, western Wyoming, and eastern Idaho to western Montana; and from western Montana northwesterly to the International Boundary and beyond 1000 miles in British Columbia to Latitude 60 and the Liard River. In Arizona and south-central Utah, the trenches separate the High Plateaus of the Colorado Plateau Province; in north-central Utah they form the eastern margin of the Basin and Range Province; and northward they occur within a belt not more than 150 miles wide closely associated with the thrusts and folds of Cretaceous and early Tertiary age. The belt is nearly 2000 miles long. All the trenches in the United States so far studied in detail are closely associated with high-angle faults and are either graben—or rotated block—type structures. Most of the trenches have been filled in part by fanglomerates, conglomerates, tuffs, and various lake and river sediments, and these have subsequently been eroded away to various degrees, so that fault-line scarps are the rule. The displacements range from a few feet to 5000 feet. Most of the deposits in which fossils have been found are latest Miocene or early Pliocene. The faulting was generally the cause of the accumulation of the sediments, but in places the faulting clearly post-dates the Pliocene deposits. In places it has continued to the present.

The high-angle, late Cenozoic faults are superimposed on the older Laramide folds and thrusts and generally trend discordantly to them. The structures of the two orogenies have not everywhere been distinguished.

The belt to which the faults belong may represent a rift zone.

KLOCKMANNITE AND ARTIFICIAL CuSe

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In the course of a study of natural and artificial copper selenides now in progress the compound CuSe was prepared by dry fusion and by hydrosynthesis, and the crystalline products were found to be physically and structurally identical with klockmannite from Sierra de Umango, Argentina. The pyrosynthetic material has the specific gravity 5.99. The minute greenish-black hexagonal plates of hydrosynthetic CuSe show $c(0001)$ (perfect cleavage), $n(10\bar{1}2)$, $r(10\bar{1}1)$, $m(10\bar{1}0)$, and the unit cell with space-group $C6/mmc$, $a = 3.93$, $c = 17.22$ kX, contains 6[CuSe], and has the calculated density 6.12. A superstructure has $a' = 12a$. Klockmannite is clearly isostructural with covellite.

SOME FEATURES IN MICROSTRUCTURE OF CARBONIFEROUS-PERMIAN FENESTRATE BRYOZOA

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Thin sections of the fenestrate Bryozoa, when etched down to finest possible ($10 - 5\ \mu$ or less) thickness, and studied under 100–150 times magnification, reveal satisfactorily the system of delicate tubules which penetrate both the dense encrusting tissue and the so-called appendages. The structure, orientation, and relation to other parts in a bryozoan colony must be studied in detail to approach understanding of their meaning and function. Some progress in this study is here reported.

Ulrich (1890) mentions the "very minute vertical tubes" of Fenestellidae and compares them with the surface pores of both Cyclostomata and Cheilostomata. Shulga (1941) calls them "capillary tubules or capillaries," which transport calcareous "skeletal substance" and deposit it "in form of lamellar crystalline matter." Condra and Elias (1944) called these developments in the massive screws of *Archimedes* "needlelike structures" and suggested that they could belong "to a simple microscopic alga" or to transverse hyphae of more complex algae. These three are the principal competetive explanations of the discussed minute tubules.

Material for the study of the microstructure of the living and Cenozoic calcareous Bryozoa has been supplied by the U. S. National Museum through the courtesy of Dr. R. S. Bassler. Fine lamellar structure of calcareous skeleton has been found in *Hornera*, but no transverse minute tubules were noticed in this or other genera examined.

Pseudopores and protuberances (unrelated to each other) in *Crisia* and related living Cyclostomata, described by Borg (1926), are nearest in size and orientation to the minute tubules in the Paleozoic Bryozoa discussed, but their other characters and details are different. Comparative study of these structures is being carried on.

RANGER BANK, MEXICO

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Ranger Bank provides a typical example of the environment in which bank sediments occur. It is located at the edge of the continental shelf off Mexico about 260 miles south of San Diego. Its flat top is 15 miles long and 2 to 4 miles wide. The shallowest depth is 67 fathoms. Prior to the war Hancock Foundation dredged a few samples from the bank, and during the war the University of California Division of War Research collected some snapper samples and under-water photographs. Examination of these materials and navigational chart notations shows that the bank top is floored by outcropping metamorphic, volcanic, and sedimentary rocks patchily covered by a few inches of residual, organic, and authigenic sand. Among the metamorphic rocks is Franciscan (?) glaucophane schist. The volcanic and sedimentary rocks are probably mostly of Miocene age. Very abundant phosphorite nodules may be from Miocene beds. Apparently, erosion by past wave action produced the flat top and left a thin veneer of sand and rounded gravel. After submergence of the bank there has been a slow accumulation of coarser sand composed of organic remains, largely foraminiferal tests, and of glauconite which occurs mostly as internal casts of Foraminifera. Present wave motion and currents are strong enough to prevent the deposition on the bank of fine muds like those of surrounding deeper areas and to produce faint oscillation ripple marks on the sand, but they are not strong enough to roll the cobbles; consequently, the cobbles and boulders are covered by encrusting organisms.

GEOLOGY OF THE CENTRAL OWL CREEK MOUNTAINS, WYOMING

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The Owl Creek Mountains of Wyoming are a central unit in the belt of Laramide ranges which outline the Bighorn Basin on the north from the Wind River Basin on the south.

In the central Owl Creek Mountains, Paleozoic, Mesozoic, and Cenozoic rocks are exposed along and peripheral to a complex pre-Cambrian core.

The oldest pre-Cambrian rocks include metasediments of clastic and pyroclastic origin, and mafic intrusives and flows. These rocks adjoin and lie within composite bodies of younger quartz monzonite and granodiorite formed during stages of dynamo-thermal metamorphism. Younger pre-Cambrian rocks include a gabbro dike swarm which is cut locally by massive granite, pegmatite, and quartz veins.

The Paleozoic and Mesozoic rocks constitute a widely recognized, essentially conformable sequence some 7500 feet thick. These sediments and subjacent pre-Cambrian rocks were deformed in late Cretaceous, Paleocene, and Eocene stages of the Laramide Revolution.

Major Laramide structures in the central Owl Creek Mountains are a series of east- and southeast-trending asymmetric folds and related thrust faults. These structures occur in curved, intersecting patterns and define a series of rhombic to lenticular segments along the range. Pronounced overturning of folds and thrusting toward the north and toward the south and southwest occur along the segments.

Cenozoic rocks include sediments derived from the elevated portions of the Owl Creek Mountains and adjacent ranges, and pyroclastic rocks derived largely from volcanic vents in the Absaroka Mountains to the west.

PRIMÄRRUMPF AND FOLD MOUNTAIN

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The W. Penck concept of a Primärrumpf was an upwarped, progressively expanding dome with rise so slow that degradation kept pace with uplift, and the area involved failed to gain altitude by reason of the diastrophic shift. Opposed to this concept is that of rapid uplift through any type of diastrophism, then stand-still and erosional degradation to peneplain levels. The applicability of the Primärrumpf interpretation to surfaces that truncate structure has been generally discredited. Where it is admitted as a possibility the uplift is attributed to warping or doming, W. Penck's postulation.

It is here contended that, whereas warping, faulting, and epeirogenic uplift in general are competent to raise land masses to high altitudes fast enough to create relief, such is not true of uplift ascribed to folding through lateral compression. The orogenic failure of folding alone is commonly, if obscurely, conceded. What is not realized is that denial of competence to develop mountain forms and altitudes by raising anticlinal structures from folding precludes the existence, ever, of first-cycle fold mountains. Instead geosynclinal tracts while undergoing compressional folding are, *pari passu*, being converted to Primärrumpf surface expression. Where a Primärrumpf might be least expected proves to be the place where it should get perfect development. Accordingly, "peneplain" remnants truncating fold structure across upwarped mountain summits are actually parts of an initial Primärrumpf surface developed at base level while fold "orogeny" was in progress.

SILICIFIED TRILOBITES FROM THE LOWER LINCOLNSHIRE FORMATION IN NORTHERN VIRGINIA

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A trilobite fauna of 18 species belonging to an equal number of genera has been obtained from the lower part of the Ordovician Lincolnshire limestone in the northern Shenandoah Valley of Virginia. The species (most of them previously undescribed) are referable to the following families: Cheiruridae, Encrinuridae, Phacopidae, Lichadidae, Odontopleuridae, Proetidae, Harpedidae, Asaphidae, and Otarionidae.

The silicified trilobite tests have been freed from the calcareous matrix by etching with hydrochloric acid. Though characteristically disarticulated, in most cases all parts of the test of each species have been recognized. This, together with the high quality of the preservation, permits a more precise diagnosis of several genera which until now have been poorly known from fragmentary material.

The free specimens make possible a study of the internal as well as the external surface of the test. In the case of the more abundantly represented forms the ontogenetic development can be traced by a more or less complete series of growth stages.

LOUGHLINITE, A NEW HYDROUS MAGNESIUM SILICATE

JOSEPH J. FAHEY (With x-ray analysis by Joseph M. Axelrod)

U. S. Geological Survey, Washington, D. C.

The name loughlinite, in honor of the late Dr. Gerald F. Loughlin, former Chief Geologist of the United States Geological Survey, is given to a new mineral from the Green River formation of southwestern Wyoming.

This mineral was first found in 1940 in the drill core of the John Hay, Jr., Well No. 1, and again in 1946 in the drill core of the Union Pacific Well No. 4, both in quantities too small for adequate investigative work. In the summer of 1947 many excellent samples were obtained from material excavated during the sinking of the shaft of the Westvaco Chlorine Products Corporation, drilled for the purpose of mining trona. These three locations are 18–20 miles west of Green River, Sweetwater County, Wyoming.

Loughlinite occurs in veins in low-grade oil shale that contains crystals of shortite. It has an asbestoslike appearance, a silica-magnesia ratio of 2/1, and gives an x-ray powder picture unlike any known magnesium silicate.

XANTHOPHYLLITE NEAR BUTTE, MONTANA

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The brittle mica xanthophyllite is described from a contact-metamorphic aureole developed by a local intrusion of leucogranite into the Hasmark dolomite near the center of section 32, T. 1 N.,R. 7 W., Highlands mining district, about 20 miles south of Butte, Montana.

Minerals associated with the xanthophyllite include pale yellowish-green grossularite, diopside, idocrase, forsterite, and recrystallized calcite.

Later hydrothermal action has converted large amounts of the forsterite and diopside to serpentine.

OBSERVATIONS ON WEBERITE AND JARLITE

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Fragments of weberite, oriented optically, gave the unit cell with space-group *Ibmm* or *Ibm2*, $a = 7.30, b = 7.05, c = 9.97$ kX, containing $4[Na_2MgAlF_7]$; $X = a, Y = b$. Poor crystals of jarlite (sp. grav. 3.87), also oriented optically, gave the unit cell with space-group $C2/m$ or $C2$ or Cm, $a = 15.99, b = 10.82, c = 7.24$ kX, $\beta = 101° 49'$; $Y = b, Z : c = +84° \pm 2°$; $\alpha = 1.430, \beta = 1.435, \lambda = 1.437, 2V = 90° \pm 10°$. "Meta-jarlite" (sp. grav. 3.65, with inclusions) gave $\alpha = 1.429, \beta = 1.431, \lambda = 1.434$, and an *x*-ray powder pattern hardly distinguishable from that of jarlite. Sharp powder photographs of ralstonite show indications of noncubic symmetry, and the yellow ochre "hagemannite" is mainly ralstonite rather than thomsenolite. These results were found to confirm and add to published results by C. Brosset (Diss. Stockholm, 1942—M.A. 10-16).

GLACIATION OF SOUTH DAKOTA (PRELIMINARY DISCUSSION)*

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Most of the Pleistocene ice that invaded South Dakota flowed in from the northeast and north. Nebraskan and Kansan drifts are present in the State, though neither has yet been identified west of the Missouri River. The fluvial Grand Island formation (Kansan), widely developed in Nebraska, is present in southern South Dakota. Yarmouth deposits and the Loveland loess (Sangamon) are present; Illinoian deposits have not been recognized.

Iowan drift (early Wisconsin) is much more extensive than was believed formerly. This drift appears to have covered all of southeastern South Dakota. It is overlain by a deflation armor of ventifacts and a mantle of loess deposited later in the Iowan substage.

There are two post-Iowan drifts, each related to a regional re-expansion of the ice sheet, which, however, was thin enough at both times to have been influenced strongly by major relief features. The older drift is extensively covered by loess; the younger, less extensive drift is nearly free of loess.

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The older drift appears to be contemporaneous with at least part of the drift in northeastern South Dakota correlated by Leverett with the late Wisconsin Mankato drift. Hence apparently either (1) both post-Iowan drifts in South Dakota are Mankato, or (2) the outer part of the drift in northeastern South Dakota, considered Mankato by Leverett, is in part pre-Mankato.

The two post-Iowan drifts possess remarkable systems of end moraines, which form successive loops across the James Valley lowland, and which are largely responsible for the arcuate pattern of the minor streams.

CAMBRIAN AND CANADIAN OF FORT ANN, NEW YORK

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The Fort Ann region contains a relatively complete section, ranging from Potsdam through the Canadian, for eastern North America, with 12 major faunal horizons. The faunas are being described, and necessary new formation names are proposed. Almost all lithological contacts are facieological, and previous formations are essentially meaningless. A summary of the section and of the essential faunal elements is presented.

The Potsdam ranges from upper Dresbach into lower Franconia. Middle and possibly upper Franconia are present in the "Theresa". The lower Whitehall is of Trempealeau age. An interval ranging from limestones mistakenly identified as upper Hoyt, through the Skene dolomite of Wheeler, carries gastropods and cephalopods of Copper Ridge affinities.

The Gasconade interval comprises sandstone, dolomite, and the Fort Ann limestone, with a rich fauna, the lower beds with Ozarkina and *Hystricurus*, the higher with "*Helicotoma*". A remarkable erosion interval separates this from the Middle Canadian division. The Upper Canadian is represented by the Fort Cassin and Providence Island.

Correlation with Vermont indicates that Brainerd and Seely's division A includes Gasconade dolomites on Franconia dolomites, the Trempealeau being missing. B includes the upper Gasconade, with the limestone facies extending down into underlying dolomites of Fort Ann section. C is missing at Fort Ann and Whitehall. It is Middle Canadian. D embraces the Middle Canadian and the Fort Cassin of the Upper Canadian.

NEW FAUNA FROM THE VERNON SHALE OF NEW YORK

R. H. FLOWER AND R. WAYLAND-SMITH

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A single bed in the middle of the Vernon shale near Oneida has yielded several hundred specimens of a well-preserved marine fauna, containing a new siphonophore, a new merostome genus, eurypterids, brachiopods, cephalopods, gastropods, pelecypods, and ostracodes. The pelecypods and eurypterids show affinities with both the Pittsford and Bertie faunas.

AQUEOUS EMANATION FROM PARICUTIN VOLCANO

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Large quantities of water vapor are emitted from the crater of Paricutin Volcano. An estimate based on observations on May 27, 1945, gives 16,000 tons per day, compared to 100,000 tons of lava emitted. The characteristics of the vapors emitted from the crater vent differ from those emitted directly from the lava vents, suggesting considerable dilution of magmatic emanations by ground waters. It is suggested that the rock alteration in many ore deposits is due in part to activated ground waters.

USEFUL ASPECTS OF THE FLUORESCENCE OF ACCESSORY-MINERAL ZIRCON

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The mineral zircon has long been known to exhibit fluorescence when exposed to ultraviolet radiation. Hitherto little practical use appears to have been made of this phenomenon. Its application is here recommended in the inspection of commercial concentrates of zircon, and of other minerals containing zircon as an impurity. Comparison of the fluorescent behavior of grains of zircon from igneous rocks of different ages, and from igneous as compared to sedimentary sources, reveals certain contrasts. The possible usefulness of such contrasts in the solution of a number of petrological problems is discussed. Reference is also made to the fluorescence of accessory-mineral apatite, and of certain other minerals found in association with zircon.

ENGINEERING GEOLOGIC STUDIES OF THE UPPER MISSOURI RIVER BASIN

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Extensive geologic studies and foundation explorations have been conducted by the Bureau of Reclamation on 20 dam sites on the upper Missouri River and tributaries during the past 3 years. A wide variety of foundation problems have been encountered at these sites, and the need and value of a complete geologic investigation and interpretation has been demonstrated at each dam site. Approximately 10 of the dam sites are located in the Northern Great Plains on soft to semihard, unconsolidated, compacted Upper Cretaceous and Tertiary sediments. In addition to the low compressive and shear strengths of the unconsolidated sediments, they contain numerous interbedded layers of bentonite and bentoniticlike clays.

The dam sites located on the Paleozoic and pre-Cambrian rocks on the east slopes of the northern and middle Rocky Mountains generally present less serious foundation problems, but wide zones of fault gouge and limestone cavities are common problems.

The proposed construction of numerous large dams on the upper Missouri River and tributaries on unconsolidated sediments presents many difficult foundation, design, and construction problems.

BRYOZOA OF THE OTTAWA LIMESTONE

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This is a brief report upon a study in progress that deals with the Bryozoa of the Ottawa limestone from the Ottawa-St. Lawrence Lowland Area. Here the region is described, the formation discussed, the fauna analyzed, and the suggested correlation indicated.

MORPHOLOGY AND RELATIONSHIPS OF THE FORAMINIFERAL GENUS CHAPMANINA SILVESTRI

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Chapmanina Silvestri is a calcareous foraminifer, of Eocene age, characterized by an imperforate double wall with an intraseptal canal system. Its growth plan is first trochoid, subsequently uniserial with buttress-tubes and peripheral chamberlets. A new genus is described, intermediate between *Chapmanina* and its presumed rotaliid ancestor. The rotaliid—new genus—*Chapmanina* lineage (calcareous) parallels in a number of features the *Arenobulimina—Lituonella—Coskinolina* series of the *Dictyoconus* lineage (arenaceous). The nomenclatural insecurity of the name *Chapmanina* is discussed.

SECOND OCCURRENCE OF BRAZILIANITE

CLIFFORD FRONDEL AND MARIE LOUISE LINDBERG

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A second occurrence is recorded for brazilianite, at the Palermo mine, near North Groton, Grafton Co., New Hampshire. The mineral occurs as a late hydrothermal product in a granite pegmatite of the quartz-core type, in the following association and sequence:

quartz—brazilianite—apatite—whitlockite—quartz (last)

The crystallographic, optical, and physical properties conform closely to those of the Brazilian crystals. Observed forms: a{100}, b{010}, n{011}, O{111}, g{$\bar{1}$11}, s{211}, x{$\bar{1}$01}, v{$\bar{3}$01}, q{$\bar{1}$21}. The crystals have an elongate, four-sided appearance due to the relatively large development of n{011} and g{$\bar{1}$11} and the near suppression of the prism zone. The crystals range in size up to about three-fourths inch along [100]. Color chartreuse yellow. Specific gravity 2.985 ± .005. Optically positive, n (Na) : $X = 1.602$, $Y = b = 1.609$, $Z = 1.623$, $X \wedge c = -20°$, $2V = 71°$ (calc.); dispesion $r<v$, faint. A redetermination of the gravity and refractive indices for the Brazilian crystals gave G 2.980 ± .005; $X = 1.601$, $Y = 1.608$, $Z = 1.620$. A chemical analysis of the Palermo crystals (by M.L.L.) gave : Na_2O 8.29, K_2O 0.20, Al_2O_3 42.85, Fe_2O_3 0.03, TiO_2 0.05, P_2O_5 38.79, H_2O^- 0.04, H_2O^+ 9.91, total 100.16. The analysis conforms closely to the established formula, $NaAl_3(PO_4)_2(OH)_4$.

CORRELATION OF THE PEARLETTE VOLCANIC ASH FROM THE GLACIATED REGION INTO THE SOUTHERN HIGH PLAINS

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Correlation of Pleistocene deposits of the Great Plains with the glacial succession of the upper Mississippi Valley presents a major problem in Great Plains stratigraphy. The presence of lenticular deposits of volcanic ash and commonly associated fossil mollusks interstratified with both the glacial and associated deposits of the Missouri Valley and the nonglacial deposits to the west and southwest affords a new and independent method of attacking this problem. These ash deposits collectively are known as the Pearlette ash and represent a single fall that can be differentiated unmistakably by petrographic characters from other late Cenozoic ash deposits of the Plains region. Pearlette ash is represented in 48 localities studied, distributed from southeastern South Dakota to west-central Texas. The associated molluscan fauna presents an unforeseen degree of uniformity throughout this entire region, and the presence of restricted species, extinctions, and first appearances confirm the contemporaneity of the several volcanic ash deposits. The Pearlette ash and closely associated fossil-bearing beds occur within the Loveland formation of Iowa (below the Loveland loess), the Upland formation of Nebraska, the McPherson formation of central Kansas, the Meade formation of southwestern Kansas and northwestern Oklahoma, and the Tule formation of northwestern Texas. In the Missouri Valley area the Pearlette zone is contained in beds unconformably overlying Kansas till and below Loveland loess and Iowa till. It is judged, therefore, that the age of these severally named formations is latest Kansan and Yarmouthian.

AGE OF CATOCTIN VOLCANIC ROCKS IN VIRGINIA*

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This paper reviews the controversy regarding geologic age of these rocks which occupy two belts in the Blue Ridge province from Maryland to central Virginia. Most of the conclusions are derived from a study of the western (Blue Ridge Mountain) belt, because contacts between volcanics and

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underlying intrusives are generally concealed in the Bull Run-South Mountain belt south of Loudoun County by the pre-Cambrian Fauquier formation, and Lower Cambrian Loudoun formation. Writers agree that the rocks of both belts are of the same age. These volcanics are believed by the writer to be older than associated granite and granodiorite, thus of pre-Cambrian age, for the following reasons:

(1) Lower Cambrian Unicoi and Loudoun formations unconformably overlie the intrusives (granodiorite and Old Rag granite) and Catoctin greenstone volcanics. They consist largely of fragments of the intrusives, and locally of fragments and conglomerates derived from the greenstone.

(2) Local evidence of intrusion of granite and granodiorite into Catoctin volcanics.

(3) Local inclusions of greenstone fragments in granodiorite and Old Rag granite, and lack of included granite and granodiorite fragments in the base of the flows.

(4) Tendency to production of "unakite" in granodiorite and Old Rag granite near contact with Catoctin greenstone.

(5) Great differences in elevation within short distances of the floor of the greenstone, and bosses of granodiorite and granite within greenstone where normally it would have been considered to be of great thickness.

(6) Composition, distribution, and association of primary copper ores in the Catoctin volcanics indicate an intrusive relationship of underlying granodiorite and granite.

SYNTHETIC REPLACEMENTS—I. DIFFUSION

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Study has been made of the replacement of calcium carbonate in water solutions at temperatures from 25° to 75°C at atmospheric pressure. Movement of the replacing ions was entirely by diffusion. First the rate of solution of single crystals of calcite was determined as a function of temperature and acidity. Then the calcite was replaced by atacamite, a reaction in which calcite is dissolved and atacamite simultaneously precipitated. The effect of the deposition of the atacamite in slowing the rate of solution of calcite was determined as a function of concentration of the reacting solutions, temperature, time, and percentage of atacamite retained at the surface of the specimen. In general, the rate of replacement was slowed logarithmically by the thickening of the replacing material. The work was extended to a study of the diffusion of nonreacting ions into calcium carbonate aggregates such as chalk and limestone before the atacamite replacement was superimposed on the diffusion process. With no excess pressure replacement penetrates but a fraction of a millimeter into chalk and limestone before the replacing atacamite blocks further access of the solutions to the calcium carbonate of the rocks.

ISOMORPHIC PHENOMENA IN THE MELILITES

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Experimental determinations have shown that $CaO \cdot 2Al_2O_3$ forms a partial solid solution series with $Ca_2Al_2SiO_7$ (artificial gehlenite). A substitution of Al for Ca is here involved, which was hitherto unknown in silicates and has been considered unlikely because of the rather large size difference of the two ions.

The soda content of melilites was also investigated, it being found that 15 per cent of the hypothetical "molecule" $Na_2Si_3O_7$ can be taken into solid solution with gehlenite. There is no solid solution of this soda member with akermanite ($Ca_2MgSi_2O_7$); thus the artificial melilites contain less than 15 per cent $Na_2Si_3O_7$, the absolute amount decreasing with an increase in the akermanite content of the mix crystals. The fact that some published analyses of natural melilites show more soda (up to 5.44 per cent Na_2O) than can be accounted for by the determined maximum of 15 per cent $Na_2Si_3O_7$ (3.85 per cent Na_2O) would indicate that more careful work on natural melilites should be done.

GEOLOGY OF WATAUGA DAM, TENNESSEE

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Watauga Dam, a multipurpose project now under construction by the Tennessee Valley Authority, is located on the Watauga River in Carter County, Tennessee. When completed, it will stand 325 feet above the river bed and will be the highest earth and rock-fill dam in the eastern United States.

Geologically, the dam is situated across the Iron Mountain thrust. The main mass of the structure rests upon quartzite strata of the Unicoi formation which form the hanging wall of the fault, but the upstream portion of it is founded on the Shady dolomite, which forms the footwall. The geologic problems which were encountered during the design and construction all were related directly or indirectly to the presence of the Iron Mountain fault. Many of the problems were due to the unusual hardness and brittleness of the quartzite and the extensive jointing produced in it by stresses resulting from thrust faulting.

IRON MOUNTAIN THRUST FAULT AT WATAUGA DAM, TENNESSEE

LELAND F. GRANT AND JOHN M. KELLBERG

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Construction of Watauga Dam by the Tennessee Valley Authority in Carter County, Tennessee, has exposed one of the larger overthrusts of the Southern Appalachians. The Iron Mountain thrust was encountered in the excavations for the spillway plaza, the spillway and diversion tunnels, the valve chamber, the power tunnel, and the dam foundation. With the exception of the spillway plaza, all exposures of the fault at this site will be covered upon completion of the dam.

The Iron Mountain fault and the Holston Mountain fault are parts of the same downfolded overthrust; the fault plane separates the Lower Cambrian clastics in the Shady Valley syncline from the underlying Cambrian and Ordovician sediments of the Valley of East Tennessee. The Mountain City window separates the Iron Mountain fault from its roots in the Unaka Mountains to the southeast.

The detailed structural features of which studies were made include: (1) folding, faulting, and jointing of the dolomite and shale in the footwall; (2) folding, faulting, and jointing of the quartzites in the hanging wall; (3) evidence of the direction of movement of the main fault and of the related faults in the hanging wall and footwall; (4) petrographic study of the variation in the deformation and alteration in both the hanging wall and footwall.

INVESTIGATION OF BENTONITIC CLAYS FOR ENGINEERING PURPOSES

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Montmorillonite-type clays are now known to be widespread and thus commonly are encountered at construction sites, or in proposed construction materials. They occur in altered igneous rocks, tuffs, and metamorphic rocks, and in sediments. These clays, the essential constituents of bentonites, characteristically swell by penetration of water into their crystal lattices, and become unusually slick through development of stable water films around the particles. Illite clays may act similarly.

Hydration pressures of undisturbed bentonitic clays may exceed 10 tons/ft.^{2}. Consequently, they can cause dislocation of structures. Thus, piers supporting the Malheur River siphon, Oregon, were shifted 1 foot vertically and 0.68 foot longitudinally. When used as aggregate, a dolerite containing 30 per cent nontronite caused excessive shrinkage and reduced durability of concrete.

Softness and instability of bentonitic and illite-containing materials account for subsidence and landsliding at many construction sites. At Anderson Ranch Damsite, Idaho, fractured and altered granites containing montmorillonite clay yielded repeatedly to landsliding during excavation.

Because of these dangerous properties of bentonitic materials, samples from construction sites and of materials to be used on Bureau of Reclamation projects are examined petrographically to (1) identify the clay minerals present from optical properties, X-ray diffraction data, and reaction to staining tests, (2) determine their abundance and mode of occurrence, and (3) establish the physical properties of the material by semi-quantitative tests, such as the free-swell test. Through application of these quick, inexpensive procedures, the need for time-consuming quantitative determinations is established, and futile testing of stable materials thus is avoided.

PART OF THE SYSTEM H_2O-H_3PO_4-$AlPO_4$

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This work is being done in connection with the growing of crystals of $AlPO_4$ and is sponsored by the Squier Signal Laboratories, U. S. Signal Corps, Fort Monmouth, N. J. Only the part of the system is being investigated which contains only solution at room temperature. Crystals form in these solutions on raising the temperatures. Hydrates of $AlPO_4$ have been found to about 140°C depending upon concentrations. Above this temperature anhydrous $\alpha AlPO_4$ (berlinite) crystallizes. The pressures accompanying each concentration at given temperatures are also being measured. Anhydrous $AlPO_4$ grown under these conditions has an inversion point from α to β within 5°C of that of quartz (573°C). It also resembles quartz very closely in many other respects.

ORIGIN OF SOME BITUMEN IN THE DEVONIAN-MISSISSIPPIAN BLACK SHALES AND THE EOCENE GREEN RIVER SHALE

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The bituminous content of widespread oil shales such as the Devonian-Mississippian black shales and the Green River oil shales has been the subject of considerable speculation. The geological histories of both formations indicate much in common.

Large positive areas such as the Ozark Dome, Nashville Dome, and Cincinnati Arch uplifted in late Ordovician time probably were regional oil structures. Erosion from late Ordovician to late Devonian exposed the localized oil reservoirs and caused dissipation of the liquid bitumen. The oil was incorporated in the dark muds to account in part for the bituminous content of the Devonian-Mississippian black shales. The Genessee black shales of New York are bituminous where they flank the Cincinnati Arch; to the east they are carbonaceous either as a result of regional metamorphism or because they were formed of plant material derived from Appalachia.

The Laramide Revolution produced the Rocky Mountains which likewise undoubtedly were large regional oil structures. The great relief promoted rapid erosion during Paleocene and Eocene which exposed the oil in the reservoirs to oxidation and inspissation. Petroliferous sediments accumulated in the intermontane basins to form the Green River oil shales.

Preservation of the active hydrocarbons required rapid burial which might have been accomplished in the Green River shales by drying up of the lakes during short intervals. Films of oil around individual grains heavy enough to settle might account for their incorporation in the bottom sediments. The Athabaska tar sands indicate that dissipation of volatile bitumens is a slow process.

The implications of this theory are: (1) The Devonian-Mississippian black shales and the Green River shales are not necessarily source beds for petroleum. (2) There was oil in the sediments in pre-late Devonian time which should encourage deeper exploration. (3) A large portion of the oil in the truncated late Ordovician structures has escaped.

PTEROTOCRINUS FROM THE KINKAID FORMATION OF SOUTHERN ILLINOIS AND WESTERN KENTUCKY

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A rich *Pterotocrinus* fauna has been collected in five widely separated localities of southern Illinois and western Kentucky from the Kinkaid formation, uppermost Mississippian of the Chester Series. Several new species can be recognized from over 1000 "wing plates" including one complete crushed calyx with "wing plates" in position. Forms closely allied to *P. depressus*, *P. spatulatus*, and *P. coronarius* will add to our knowledge of the evolution of the genus. In addition *P. bifurcatus*, common in the Glen Dean formation, has also been found in the Golconda formation.

REDWALL LIMESTONE OF NORTH-CENTRAL ARIZONA

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The Redwall limestone constitutes the entire Mississippian System in north-central Arizona where it was studied in the Sycamore Canyon-Jerome-Black Mesa area. Four distinct lithological units can be recognized and general correlation made with the standard section. Disconformities below and above separate the Redwall from the underlying upper Devonian Island Mesa (?) and Martin formations and the overlying Permian (?) Supai formation. The Redwall limestone reaches a maximum thickness of about 275 feet and thins to the east and southeast.

In ascending order the basal member consists of white, crystalline, partly oölitic limestone overlain by a fine-grained, cherty, porous limestone member. A meager, poorly preserved fauna indicates that these beds are Kinderhook in age. Member three is a massive, coarsely crystalline, cliff-forming limestone which contains an excellent fauna of early Osage age. The top member is gray, dense, micro-oölitic limestone of Osage age possibly as young as Keokuk.

Widespread solution during and after the formation was deposited has produced rubble breccias, washed in red silty muds, and developed cave breccias.

Extending under the Colorado Plateau to the northeast, the Redwall should make a very suitable reservoir for oil accumulation. Lithologically there is a striking resemblance to the prolific oil-producing Hunton limestone of Siluro-Devonian age in Oklahoma.

MINOR MORAINES IN SOUTH DAKOTA AND MINNESOTA

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County index maps of glaciated areas of South Dakota and Minnesota show scattered areas of definite pattern similar to those of the Mankato lobe in Iowa.

The areas of best-developed pattern are in southeastern South Dakota, adjacent to James River, and in southern Minnesota, in Brown, Cottonwood, Martin, and Watonwan counties. The pattern is interpreted as resulting from the presence of deposits made annually in the course of glacial retreat. Most of these have low relief and constitute minor moraines. The front of the ice as outlined by them is not in accord with the general front of retreat as deduced from the major recessional moraines mapped by earlier geologists. Minor moraines, where present in areas mapped as recessional moraines by others, do not generally parallel them in strike. The greater part of the areas of minor moraines lies outside these areas of recessional moraines as mapped by others. The areas are generally of relief less than 30 feet per square mile.

A second type of pattern, present in Morrison County, Minnesota results from the presence of low swells up to half a mile in width, separated by intervening swales, of equal width, with relief of approximately 50 feet. The county index map of Hubbard County, Minnesota, discloses an area of pattern of crowded ridges having a relief of 200 feet. Still other areas of other parts of the two States have areas of patterns of variable distinctness, size, and character. Materials are largely till.

TURONIAN AMMONITES FROM NEAR GREYBULL, WYOMING

OTTO HAAS

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Five ammonite species and some specimens of *Inoceramus fragilis* were found at a new locality in the Cody shale. Two of the ammonites species attain sizes of 350 and even 400 mm. One of them, the commonest fossil at the locality, differs from "*Mortoniceras*" *shoshonense* in specific characters only and reveals the hitherto unknown mature stage of the genus to which both these species have to be referred and which it is intended to detach, under a new name, from *Texanites*. The other large species is a *Mantelliceras*. Another ammonite is a *Metoicoceras*, closely related to, if not conspecific with, *M. whitei*.

The *Mantelliceras*, the *Metoicoceras*, and the *Inoceramus* suggest Lower Turonian, thus extending the hitherto assumed stratigraphic range of the Cody shale—believed to be a facies rather than a stratigraphic unit—considerably downward. The large ammonite closely related to "*Mortoniceras*" *shoshonense* proves that the genus hitherto represented only by this Niobrara (= Coniacian) species appears considerably earlier.

A paper describing and illustrating this assemblage is in preparation.

ALLUVIATION OF THE WHITEWATER VALLEY, MINNESOTA

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A new cycle of alluviation, apparently caused by the effects of soil erosion since white settlement, is aggrading the flood plain of Whitewater River, a tributary of the Mississippi River in southeastern Minnesota. Auger borings show that the former flood plain and bordering low alluvial terraces were covered by black, peaty soils, now buried by brown sandy silt to average depths of 1.3 to 5.7 feet on representative cross-section lines. The new deposits aggregate about 13,000 acre-feet in the main valley and lower parts of principal tributaries, equivalent to erosion of about 1 inch from the drainage basin of 320 square miles, and there is much more sediment in the smaller tributary valleys. Comparison with suspended load records suggests that sediment exportation to the Mississippi is less than 25 per cent of that being produced. Studies of cross sections indicate that continuance of present sedimentation rates will increase flood-stage heights 1.1 to 2.4 feet, and corresponding inundation areas 0.6 to 15.7 per cent, in the next 25 years. The village of Elba, on one of the few low terraces still above the rising flood plain, is obviously faced with severe flood hazards, and ground water now stands several feet deep in cellars under houses in the village of Beaver. Sandy alluvial fans at the mouths of numerous gullies in high alluvial terraces, and bouldery fans below gullies in talus slopes under the Oneota-Shakopee dolomite cliffs, are conspicuous and cause considerable damage, especially to highways, but constitute a comparatively small part of the volume of sediment.

GEOLOGY OF THE KANOPOLIS DAM, KANSAS

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Kanopolis Dam is a rolled-earth structure, 3 miles long and 135 feet high, across Smoky Hill River in central Kansas. Cretaceous dark shale with several sandstone layers forms the abutments, underlain by Permian red and green shales and siltstones, which continue under the valley. Normal river discharge is through a concrete-lined tunnel in the Permian strata, and the emergency spillway is excavated through a ridge of Cretaceous strata about a mile from the dam, with concrete sill, and toe-wall extending 25 feet into shale as a precaution against erosion.

Most of the dam rests on 10 to 50 feet of sandy loam and gravelly sand of the flood plain and bordering low terrace, compacted by rolling after stripping 2 to 10 feet of clay and loam. No cut-off is provided, but the natural clay blanket was left undisturbed, and the river channel was blanketed with clay for 1600 feet upstream, to decrease underseepage. Weathered shale and colluvial clay near the foot of the abutments required stripping to a maximum depth of 25 feet. Seepage from the Cretaceous sandstones caused minor construction problems.

Impermeable fill material was chiefly from the valley alluvium, but less material was available, within allowable moisture limits, than indicated by preliminary explorations during an unusually dry period. Sand for permeable sections of the dam, and for part of the concrete, was obtained from Pleistocene terrace deposits high on both abutments. Several quarries in Cretaceous calcite-cemented sandstone lentils furnished most of the rock for concrete aggregate and riprap.

STRATIGRAPHY AND ORIGIN OF BAUXITE

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Known bauxite deposits range in geologic age from Devonian to Recent. Those of principal commercial importance, however, are of Middle Cretaceous (Albian), Upper Cretaceous (Senonian), Lower Eocene, Oligocene, and Recent age. Bauxite deposits of Albian age occur in the Var district in France. Bauxite of Senonian age is found in the Herault district in southern France and in the south of Greece. Deposits of Lower Eocene age occur in Hungary, Yugoslavia, and the United States. Oligocene bauxite is found in Jamaica, while deposits of latest Tertiary or Recent age include the important tropical bauxites of the Guianas and Brazil in South America, those of French Guinea and Gold Coast in Africa, and those of India, Malaya, and Netherlands Indies in Asia and Australasia. The low-grade bauxite of Russia is Devonian and Carboniferous.

Bauxite deposits are significant stratigraphically since they mark long periods of emergence, quiescence, and subaerial weathering. Bauxite may result from the weathering of any one of many rocks or their weathered derivations. However, rocks of originally high or moderately high alumina content may lend themselves more readily to bauxite formation. Important bauxite deposits are known to occur on limestone, such as those in central Europe and the Mediterranean region; on granite, diorite, and metamorphosed volcanics and sediments, as those in the Guianas, Malaya, and Netherlands Indies; on nepheline syenite, as those in Arkansas, U. S. A., Pocos de Caldas, Brazil, and the Los Islands, French Guinea; on schists and phyllites, as in the Gold Coast; on basalts, as those in central India; and on sedimentary clays, as those in southern Georgia and Alabama, U. S. A. Climatic conditions govern bauxite formation to an important extent.

SOME ASPECTS OF REGIONAL METAMORPHISM IN NORTHERN MANITOBA

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Argillite, graywacke, arkose, and basic volcanic rocks of the Snow group in northern Manitoba grade into Kisseynew schists and gneisses. Isograds of regional metamorphism trend east-west, and intensity of metamorphism increases from south to north. However, the isograds in arenaceous and volcanic rocks occur at a more northerly latitude than those in argillaceous members. Consequently it is inferred that these finer-grained rocks are more sensitive to effects of regional metamorphism than are the coarser-grained varieties, and this sensitivity persists to rocks of the highest grades of metamorphism. The zones of regional metamorphism characterized by the presence of staurolite and sillimanite are well developed in sedimentary rocks of appropriate composition and grade into one another, but no kyanite was found anywhere in the area studied. It is concluded that the staurolite zone extends into the zone normally distinguished by kyanite. Explanations are sought for the lag in degree of regional metamorphism of arenaceous and volcanic rocks as compared with fine-grained sedimentary rocks, and for the lack of diagnostic kyanite.

ENGINEERING GEOLOGY AT THE PALISADES DAMSITE

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An earth- and rock-fill dam 270 feet high with a crest length of 2100 feet is contemplated on the Snake River in Idaho about 44 miles (airline) east of Idaho Falls, Idaho. Bedrock is a thick series, dipping 30° eastward toward the right abutment, of compacted but relatively uncemented clays, silts, sands, and gravels, intruded by a thick andesite mass. Foundation exploration consisted of surface geologic mapping supplemented by laboratory testing and subsurface exploration.

This paper describes the extensive geological studies through which an understanding of site conditions was secured and complex foundation problems were solved. A determination of the intrusive or extrusive origin of the andesite body in the left abutment was critical in formulating the exploration program, defining the engineering geological problems, and insuring that the large spillway and outlet tunnels would be located entirely within andesite. Co-ordinated surface examinations and petrographic studies proved this igneous body to be an intrusive, sill-like mass. Bentonitic clays in the foundation sediments were tested to determine their behavior under the conditions to be imposed by the structure. An ancient landslide mass on the right abutment was located, explored, and the physical characteristics of the slide debris determined. Studies on the origin, nature, and permeability of the sedimentary series were conducted to estimate the probable amount of water seepage through the lenticular sedimentary strata. Field and laboratory methods of conducting the investigations and assembling and presenting the data to the engineer are discussed.

THE CHATTANOOGA SHALE TYPE AREA*

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The Chattanooga shale in the vicinity of Chattanooga, Tenn., consists of three members: an upper and a lower black shale and a middle gray shale. Conodonts, for the most part poorly preserved, are present in all three members. They were collected at the type locality of the Chattanooga shale on Cameron Hill in Chattanooga; and near Apison, Tenn., 16 miles east of Chattanooga. At the Apison locality, the upper black shale member contains lower Mississippian conodonts and is correlated with the Sunbury shale of Ohio. The lower black shale member at both localities contains conodonts that correlate it with the Huron shale of Ohio, a formation that the U. S. Geological Survey classifies as Upper Devonian. The middle gray shale member contains Huron conodonts, but its age is equivocal as J. H. Swartz has reported macrofossils from it which he considered to be of early Mississippian age. In the present paper, Swartz's conclusions on the age of the Chattanooga shale in the type area and also his correlation of its three members with the Devonian-Mississippian black shale sequence of northeastern Tennessee and southwestern Virginia are discussed. The presence of Huron conodonts in the lower black shale member of the Chattanooga disproves the thesis, held by some workers, that, as a unit, the Chattanooga shale is younger than the black shale sequence of the North-Central States.

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CONODONT FAUNAS, CENTRAL MINERAL REGION, TEXAS*

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The conodont faunas of the Devonian and Mississippian formations of the Central Mineral region, Texas, are described. Material studied consists of thousands of exquisitely preserved, mostly whole conodonts obtained from approximately 300 collections; majority of collections are from measured sections. Described faunas are from:

A. Barnett formation; Mississippian

Includes redescription of P. V. Roundy's types.

B. Chappel limestone; Upper Devonian(?) and Mississippian

Chappel regarded as mappable unit below Barnett and above Ives breccia. Five conodont faunal zones recognized; each zone, except highest, has fauna similar to published one:

(1) Pre-Burlington fauna, (2) Pre-Welden fauna of Oklahoma, (3) Branson and Mehl's Chouteau fauna of Missouri, (4) Bushberg and Hannibal faunas of Missouri, (5) Grassy Creek fauna of Missouri.

P. E. Cloud, Jr., has correlation chart, dated 6/18/46, on file with the Committee on Geologic Names, of the U. S. Geological Survey. He, apparently on evidence other than that afforded by conodonts, would limit Chappel to rocks of Chouteau and Fern Glen age (*i.e.*, rocks containing three highest Chappel conodont faunal zones). Cloud does not recognize presence of rocks of Hannibal age and regards Ives breccia as equivalent of Grassy Creek shale, Saverton shale, Louisiana limestone, and Glen Park formation. Writer of present abstract regards Ives as older than these formations.

C. Unnamed stratigraphic unit underlying Ives breccia. Its fauna resembles that of Upper Devonian Genundewa limestone lentil of Geneseo shale of New York.

D. Bear Spring formation; Middle Devonian.

E. Pillar Bluff limestone; Lower Devonian.

F. Ellenburger group; Lower Ordovician.

Distacodid conodonts, presumably from Ellenburger rocks, remanié in some collections.

Paper also records presence of poorly preserved or scanty conodont material in Lower Devonian Stribling formation; in Upper(?) Devonian Zesch formation; in Ives breccia; and in the limestones that fill cracks in the Ellenburger rocks.

PSEUDO-EX-SOLUTION INTERGROWTHS DUE TO PERITECTIC REACTIONS INVOLVING PARTIAL DISSOCIATION

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In a partial study of the NiAs-NiSb system, experimental results show that these substances form a complete solid solution series after fusion in vacuo. On heating, however, NiAs partially breaks down above 850°C and slowly at 500°C to form Ni_3As_2 (artificial maucherite) according to the peritectic reaction as noted by Vigouroux:

$$3NiAs \rightarrow Ni_3As_2 + As\uparrow$$

On addition of antimony to the nickel arsenide lattice, the structure is stabilized, and this dissociation does not occur to any marked extent when between 30 and 40 atomic per cent of NiSb is present.

Intergrowths produced from both artificial and natural niccolite consist of both a blade and a net type resembling textures usually ascribed to unmixing of solid solutions. A very similar natural net

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type of intergrowth of niccolite and maucherite found in a specimen of ore from the Sudbury district, Ontario, is hence interpreted as due to partial dissociation of niccolite. This dissociation is due either to a post-niccolite heat effect or to a reduction of confining pressures while high temperatures still prevailed. Although the reaction involves a rearrangement of Ni and As atoms to form the lattice of "maucherite", and since the original pure niccolite is in no sense a solid solution, the prefix is necessary in describing the resulting intergrowths as a pseudo-ex-solution type.

Work on artificial pyrrhotite-pentlandite intergrowths suggests that at least some of these may be similarly related to a peritectic reaction involving the partial loss of sulphur from nickeliferous pyrrhotite solid solutions. However, since the original host is a solid solution and migration of nickel atoms to the pentlandite segregations occurs during heating, the resulting intergrowths must be regarded as true ex-solution effects.

PEGMATITES OF THE EIGHT MILE PARK AREA, COLORADO

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The Eight Mile Park area, just west of Canon City in Fremont County, Colorado, is a plateau of 30 square miles roughly bisected by the Royal Gorge of the Arkansas River. The underlying rocks consist of three units whose contacts strike northeast. The northwestern batholith of Pikes Peak granite is separated by a narrow belt of Idaho Springs schists from the southeastern body of injection gneiss. Large pegmatite bodies, many of which have been mined for feldspar and mica, occur in both the granite and the schists along the batholith margins. Those bodies in the granite are flat-lying sheetlike masses that transect the granitic flow structure. Those in the schist are moderately to steeply dipping sills along the metamorphic foliation. The latter are characterized by a well-developed zonal structure consisting of border, wall, intermediate, and central zones. Hydrothermal replacement units, which are also strongly developed in this type of body, characteristically lie along the footwall contacts between central and intermediate zones and replace parts of both. The sheetlike bodies are marked by less definite zoning and weakly developed hydrothermal units. The total number of mineral species found is 35. Among the rarer species, which occur only in the replacement units, are fremontite (the type locality) and beyerite.

PETROLOGY OF THE MONTANA PRE-CAMBRIAN CARBONATE ROCKS*

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The pre-Cambrian Cherry Creek series of southwestern Montana contains several formations of dolomitic marble interbedded with many other metamorphic rock units. The entire series has been intricately folded and locally faulted. The sequence is further complicated by a variety of intrusive rocks, both pre- and post-metamorphic in age, and by a regional change in the grade of metamorphism. The marble beds are extremely useful as marker horizons in deciphering the structure and correlating stratigraphic sequences between the various Cherry Creek areas. In the region southwest of Ennis two marble horizons of unequal thickness occur. In the Tobacco Root Mountains east of Sheridan only the thinner formation is present. Both were observed south of Dillon.

Locally the marble beds have been mineralized with deposits of talc, copper, manganese, and graphite. The Dillon graphite deposit, which occurs chiefly in gneiss, appears to be controlled structurally by fractures from the apex of a fold in the marble. Silicification and serpentinization are local conspicuous features. In some places contact minerals have been developed.

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TURRET CORUNDUM DEPOSITS, CHAFFEE COUNTY, COLORADO

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The corundum deposits near Turret, Chaffee County, Colorado, have been known since about 1890. The best-known occurrences are near the abandoned Calumet Iron mine in a thin horizon of sillimanite- and graphite-bearing schist of Pennsylvanian age, which lies near the contact between garnet-bearing marble (metamorphosed Leadville limestone) and a mafic igneous rock. The corundum crystals, some of which attain a diameter of ½ inch, are deep blue. A few contain fracture-free parts.

In a less well known deposit, just south of Turret, corundum is disseminated throughout the central part of a 50-foot zone of chlorite rock that lies within pre-Cambrian muscovite-garnet and quartz-biotite schists. Much of the coarse chloride occurs in veins and appears to be hydrothermal in origin. At the southeast end of the deposit a marked zonal structure is developed by the alternation of coarse chloride layers with layers of garnet and actinolite rock. Other minerals are: quartz, plagioclase, biotite, anthophyllite, hoegbomite, spinel, and magnetite.

It is noteworthy that in the first deposit corundum occurs as thin basal plates whereas in the second the grayish-blue crystals are barrel-shaped, tapering prisms.

RELATION OF GOLD DEPOSITS TO STRUCTURE, YELLOWKNIFE, NORTHWEST TERRITORIES

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The larger gold deposits along Yellowknife Bay are in basic volcanic flows or greenstones of Archean age. The volcanic rocks have undergone several periods of deformation, and the ore deposits were formed along some of the earlier fault or shear zones and have been displaced by later faulting. The pattern developed by both early and late faulting is described.

OPTICAL PROPERTIES OF COMMON CLINOPYROXENES

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An improved set of optical-property curves for common rock-forming clinopyroxenes has been prepared. The basis for drawing the curves was furnished by 35 new analyses and from data taken from the work of Bowen, Schairer, and others on synthetic end numbers of the series. A large portion of the clinopyroxene field is poorly represented or not represented at all in the available data so that further revision of the curves will be necessary as specimens to fill the gaps in the present data become available.

The effect of Al_2O_3, Fe_2O_3, Cr_2O_3, MnO, and TiO_2 on optical properties is discussed as well as the effect of exsolution of lamellae of orthopyroxene.

The chemical analyses were financed by a grant from The Geological Society of America and by Princeton University.

MOTHER LODE FAULT ZONE BETWEEN THE TUOLUMNE AND STANISLAUS RIVERS, CALIFORNIA

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The Mother Lode fault zone is a major northwest-trending structure in the Sierra Nevada. From Tuolumne River northwestward to the vicinity of Sullivan Creek it is relatively narrow and consists of anastomosing member faults having a braided pattern on the map. Fault-bounded rock masses crop out as lenticular areas elongated with the trend of the zone. Between Sullivan Creek and Stanislaus River, where the zone widens to a 1- to 2-mile belt, the pattern is one of bifurcating faults, the branches in general striking somewhat more westerly than the eastern boundary fault, and being less closely spaced than the member faults farther south. Most of the faults of the zone dip steeply eastward, some are approximately vertical, and a few dip westward.

Within the fault zone are prominent areas and belts of fault breccia, cataclasite, and mylonite, which locally may be scores or hundreds of feet wide. Lenticular bodies of limestone, generally intensely brecciated and recrystallized, occur along fault lines; in some cases evidence suggests such limestone has been squeezed into its observed position as a mobile mass, a piercement structure.

Within this segment of the Mother Lode, a great majority of the gold deposits are along the eastern boundary fault of the zone. Such selective localization along this fault of the system suggests that it may extend to greater depth, or that, because of a greater amount of tectonic movement along this surface during the ore-forming epoch, channelways along it were opened more frequently.

DEGLACIATION OF A CONTINENTAL GLACIER BASED UPON STUDIES MADE IN GREENLAND

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The continental glacier of Greenland is surrounded by a periglacial land area with average width 30 and maximum 125 miles. The glacier form is that of a glorified cake of thin batter. Except within an intramarginal zone of about 50 miles breadth, its surface is so flat that the slope, though always outward, is imperceptible to the unaided eye. At all times the glacier is overlaid by a layer of strong outblowing winds which has a thickness of about 3 kilometers. This has been shown by daily balloon observations made through years from four marginal stations of the University of Michigan, and from two by the Wegener (German) expeditions.

Deglaciation proceeds by surface downmelting of the glacier during summer. The superglacial meltwater flows outward, descends through crevasses of the intramarginal zone, and issues from beneath the glacier front highly charged with the rock debris of all sizes from that of silt to large boulders. According to the relief and the general slope of the periglacial land area, the meltwater either: (1) flows away in streams; (2) flows along the glacier border as a marginal meltwater river; or (3) floods a low area within a marginal outwash apron.

At the close of the summer season melting ceases, the surface layers of the glacio-fluvial rivers or plains dry out and become deflation areas under the winter winds of the glacial anticyclone. The silt is deposited outside as loess, and the sand as dunes after sandblasting all exposed boulders and changing them into ventifacts. On the outwash surface is left an armor band of pebbles. These glacio-fluvial and glacio-eolian deposits have characters that are easily distinguished from the glacial ones which are laid down beneath the glacier.

GLACIAL, GLACIO-FLUVIAL, AND GLACIO-EOLIAN DEPOSITS OF THE STATE OF IOWA

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The area of the State of Iowa was in Pleistocene times the border region of four successive glaciations, heretofore referred to as the Nebraskan, Kansan, Illinoian, and Wisconsin. In addition to the glacial deposits, there should have been glacio-fluvial and glacio-eolian ones laid down outside on their respective periglacial areas. The areas occupied by the glaciers themselves are indicated by glaciated rock surfaces wherever bedrock is exposed.

With exception of the latest glacial deposit, whose surface is free from loess, glacial deposits in Iowa are in part hidden under the glacio-fluvial and glacio-eolian deposits of later glaciations. In order to map them, resort has been had to the drill records, thousands of which are on file at the office of the Geological Survey of Iowa or published in its reports. This study has revealed for each of the three earlier glaciations markedly different identifying characteristics.

The three earlier glaciations sent overlying lobes into the State from the southeast, each in turn less extensive than its predecessor, and with the earliest covering less than half the State. During deglaciation each of these lobes had marginal meltwater rivers which have cut deep into the bedrock. Their now-weathered glacio-eolian deposits lie to the northwest as the thin "gumbotil" which is largely covered.

Two successive later glacial lobes (Late Illinoian and Wisconsin) entered the State from the north, and their deposits are surrounded by outwash aprons and outer heavy glacio-eolian (loess) aprons. These glacio-fluvial deposits, one above the other, have heretofore been given the names Buchanan and Aftonian gravels and Iowan till, the surrounding glacio-eolian deposits, Peorian loess. Each of the outwash aprons displays a surface pebble-band and numerous scattered ventifact boulders which are hardly to be distinguished from those observed on the outwash which surrounds the Greenland glacier.

STRUCTURE AT KIRKLAND LAKE, CANADA

HAROLD HOPKINS

The structure has been influenced by faults of several ages. Rocks present in the area are Keewatin lavas and agglomerates, Temiskaming sediments, and Algoman intrusives. The ores occur in the sediments and later intrusives and are cut by quartz diabase dikes.

The north and south margins of the 2-mile-wide sedimentary belt are highly sheared by faulting, and this belt of younger rocks appears to be in a fault trough or graben; the older Keewatin rocks are outside the marginal fault zones.

The several Algoman intrusive stocks have their larger axes roughly paralleling the strike of the sediments, have a general westerly plunge, and a divergence in dips of the north and south contacts causes an increase in width with depth.

The vein structures are thrust faults and associated tension fractures. The main vein fault, the Kirkland Lake fault, occurs slightly north of the center of the sedimentary belt, strikes N. 67° E., dips steeply south, and, cutting through the sediments and intrusives, has a thrust of 1,400 feet. Vein faults of smaller movements branch off this fault on the footwall side in the east half of the camp and on the hanging wall side in the west half with the tension fractures showing the same relationship.

Post-ore faulting of several ages is evident; the earliest is a horizontal movement along the Kirkland Lake fault followed by strike faulting and rotatory cross faulting, each of two ages.

SURVEY OF CERTAIN DEVONIAN-MISSISSIPPIAN TRANSITION FLORAS. PART I: GEOLOGICAL CONSIDERATIONS; PART II: PALEOBOTANICAL CONSIDERATIONS

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A proportionately large number of plant species with structure preserved have been collected and in part described from the Ohio, Waverly, New Albany, and comparable shales. Some of these fossil plants belong to groups characteristic of older Devonian horizons; others belong to groups characteristic of the Mississippian and early Pennsylvanian, while many are unknown from other horizons.

This analysis suggests the occurrence of a localized "transitional" flora. Problems relative to its geological and geographical occurrence and distribution, to conditions of deposition and preservation, and consideration of possible phylogenetic relationships of this flora form the bases of this paper.

EVALUATION OF CALICHE-COATED PEBBLES IN GLACIAL CHRONOLOGY*

ARTHUR D. HOWARD

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At the 1946 meeting of the Geological Society attention was directed to a study of the possible relation between thickness of caliche shells on pebbles and relative ages of drift in northwestern

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North Dakota and northeastern Montana. One of the reasons advanced for the indeterminate results obtained was insufficient study. Hence, observations were continued during the summer of 1947, incidental to the larger study of the glaciation of the region.

The results remain negative. Greater variations in thickness of caliche were found within single exposures than in exposures of presumably different drifts. It was impossible to arrive at reliable average thicknesses because of the small number of properly shaped and oriented pebbles and the difficulty of making sufficiently precise measurements. Crusts of superficially uniform thickness are quite irregular when measurements of hundredths of an inch are involved.

Among the factors which may be responsible for the wide variation in thickness of caliche shells are: (1) differences in original lime content of the several drifts, (2) variations within the individual drifts, (3) relatively imperceptible textural differences, (4) differences in elevation with attendant small climatic variations, (5) direction of exposure, influencing such factors as rate of drying, and (6) surface slope and vegetative cover, affecting runoff. Lithology of the pebbles seemed to have little influence; the caliche was not noticeably thicker on limestone pebbles than on other rock types.

GLACIAL DRIFTS OF NORTHEASTERN MONTANA AND NORTHWESTERN NORTH DAKOTA*

ARTHUR D. HOWARD

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Four glacial drifts are tentatively identified on the basis of combinations of the following criteria: lithology, texture, degree of compaction, structure, intervening soil, relative freshness of moraines, divergent moraines, and general geomorphic relationships.

A very fresh-appearing moraine, probably of late Wisconsin age, trends northwest across North Dakota entering Canada at the Montana line. The drift is characterized by a preponderance of limestone and dolomite pebbles.

An older moraine, of similar lithology, but much less continuous and more dissected, diverges from this moraine in northwestern North Dakota and strikes west into Montana. A lobe of this ice protruded far to the south along an upland depression which may represent the course of the Missouri when it flowed northeast to Hudson Bay. The wake of this ice lobe is marked by a succession of till "bars," possibly annual recessional moraines.

A still earlier drift, characterized by almost equal proportions of granite, metamorphics, and limestone and dolomite, with boulders up to 10 feet, extends south to the Missouri over broad areas and in places extends across the river. At one locality this till is separated from a still older one by an immature soil.

The oldest drift, which extends 20 to 60 miles south of the Missouri, is generally more compact and has fewer and smaller boulders than the others. In this region, it has many waterworn quartzitic pebbles derived from Flaxville gravel. Closed depressions are rare in this drift.

The region is so far from type Pleistocene localities that no attempt at regional correlation is being made at this time.

EOCENE ALCYONARIA IN NEW JERSEY

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Two new species of pennatulids and one new species of gorgonid have been found in the Eocene Vincentown formation of New Jersey. The pennatulids belong in the genus *Graphularia*, representatives of which occur in the Eocene of England and Libya. The gorgonid is assigned to the genus *Gorgonella*, a species of which has been recorded from Miocene beds in Italy, but no representative of which appears to have been reported heretofore from any Eocene formation.

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LOWER PALEOZOIC BRACHIOPOD FROM FLORIDA

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Two ventral valves of a large, undescribed species of the brachiopod genus *Lingulepis*, having elongate, acutely pointed beaks, were found in the bottom core of the Sun Oil Company Langston No. 1 well in the extreme northeastern corner of Dixie County, northwestern Florida. They came from a depth of 3670 feet and are preserved in a fine-grained micaceous sandstone that lies near the base of the Paleozoic section at that locality. As species of *Lingulepis* with this kind of beak on the ventral valve are known only from Upper Cambrian and Lower Ordovician beds, the formation from which these two valves came must be of Late Cambrian or Early Ordovician age.

SYNTHETIC REPLACEMENTS—II. FORCED FLOW

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Solutions were forced through chalk and limestone to determine the relationship between replacement and permeability. Rates of flow of nonreacting solutions were first determined, and replacing solutions were then substituted. Replacement was studied as a function of temperature, pressure, and concentration of replacing ions. The ratio of rate of reaction to rate of movement of solutions determines whether the boundary between replaced and unreplaced rock is sharp or gradational.

PALEOPEDOLOGY—THE APPLICATION OF SOIL SCIENCE TO GEOLOGY

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Paleopedology utilizes soil science and the extensive coverage of the United States by maps of soil surveys and applies the knowledge of soil development and classification to the unravelling of geologic history. Soil is the result of biologic and chemical activity conditioned by vegetation, climate, parent material, physiography, and time. Zonal, intrazonal, and azonal soils grade from those with well-developed to poorly developed profiles. The parent material may be consolidated or unconsolidated rock in place or transported. Over a long period of time, if other conditioning factors remain unchanged, soils from different parent materials may lose their differentiating characteristics. Physiography and the source and alteration of the parent material are items of primary concern to geologists. Geologically, soils may be used to identify old erosional surfaces, to differentiate glacial drifts, to determine physiographic history especially in dissected areas, to locate ground-water reservoirs, and in many places as a basis for geologic mapping. Paleopedology has been applied by the writer to problems in the glaciated and unglaciated areas of eastern Ohio and in the Piedmont of the Carolinas, and found to be of great advantage.

APPLICATION OF FIELD AND LABORATORY GEOLOGY TO ENGINEERING WORKS

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The steadily increasing demand by the engineering profession for more comprehensive geologic investigations in the field and laboratory is forcing a rapid expansion in the application of geology and related sciences to the reconnaissance investigation, design, construction, and maintenance of engineering structures. For the construction of features such as successful canals, powerhouses, pumping plants, dams, and other structures, a thorough understanding of natural site conditions is a fundamental requisite; the necessity, from both technical and economic viewpoints, of adapting increasingly large and complex structures to increasingly poorer sites requires that design and construction engineers be supplied with precise information on the composition and behavior of natural foundation and construction materials.

The manner in which the objectives, functions, and operational methods of the engineering geologist are expanding to meet these requirements is described; and special emphasis is placed on the increased use of petrographic, geophysical, soils mechanics, and materials testing techniques as well as the special research and testing aids derived from chemical, physical, hydraulic, mathematical, and X-ray analyses. The range and variety of problems amenable to direct solution, interpretation, or contributory aid by the engineering geologist are outlined by presenting examples and discussing the sequential stages of investigation generally followed for various structures. The viewpoints of the engineer, geologist, and laboratory specialist are compared, and attention is given to the vital importance of mutual exchange of ideas and continuous co-ordination between these groups to insure that the most effective exploration and testing procedures will be selected and results interpreted with due regard for design and construction practices.

FLOW AND CREEP OF ROCKS AND THE STATISTICAL THERMODYNAMIC THEORY OF REACTION RATES

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Experimental data on the plastic deformation of rocks are examined in the light of the absolute reaction-rate theory of Eyring. Analysis is made of the data of Griggs and others on flow of rocks under high confining pressure and creep under constant load. The thermodynamic change-of-phase theory of Goranson is discussed. Distinctions and similarities of points of view are considered.

It is shown that a rock deforming plastically may be simulated by a coupled system of elastic springs and dashpots, the variable characteristics of the latter being determined by the relative rate of slipping of neighboring units of flow under the applied shearing stress. From statistical mechanical considerations a general relation is derived for the net rate at which flow units thus jump forward over their "potential barriers" from one equilibrium position to another. Parameters of the equation are the average "free energy of activation," the average volume of a "hole" into which a flow unit jumps, and the elastic constant of the "springs" in the mechanism. The significance of these various parameters is discussed in relation to the structure of single crystals and polycrystalline aggregates. Geological implications are considered.

NEW PENNSYLVANIAN CLISIOPHYLLID CORALS

RUSSELL M. JEFFORDS

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Clisiophyllid corals have been identified throughout the Pennsylvanian section in the Midcontinent area, but only locally do they occur in abundance. Specific separation of corals referred to *Dibunophyllum* Thomson and Nicholson (1876) requires recognition of small but consistent differences that are determined from transverse and longitudinal sections. External form and features of the calyx are of minor value in classification. *Axophyllum* Edwards and Haime (1850) seems to have no basis for recognition at this time, and most American species previously placed in *Axophyllum* probably should be assigned to *Dibunophyllum*.

Two new Pennsylvanian species of *Dibunophyllum* are described and illustrated. One occurs in the Oologah limestone (Desmoinesian) of Oklahoma, and the other in the Dover limestone (Virgilian) of Kansas.

SEPTAL DEVELOPMENT IN SOME PORPITID CORALS

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Classification of the corals included in the family Porpitidae Moore and Jeffords (1945) depends importantly on the nature of the theca, peculiarities in form of the corallite, and arrangement and character of the major septa, minor septa, and fossulae. The tetrameral pattern of the septa that is caused by the insertion of major septa at only four points permits positive identification of the protosepta in many of the species now assigned to this family. The genotype species of *Cumminsia*, *Dipterophyllum*, and *Gymnophyllum*, and most species in the other genera as well, are characterized by a marked cardinal fossula, a shortened cardinal septum, and moderately well developed alar pseudofossulae. The genotype of *Baryphyllum* and some species currently assigned to *Hadrophyllum*, however, have a strong cardinal septum and a distinct counter fossula that contains a shortened counter septum.

Examination of specimens of the genotypes of *Baryphyllum* and *Gymnophyllum* indicates that a series of individuals exhibiting successive growth stages furnish information on the ontogenetic development in the same manner as serial sections of cylindrical corallites. Gerontic specimens of the genotypes of *Cumminsia*, *Baryphyllum*, and *Gymnophyllum* differ notably in appearance from the more youthful corallites.

GEOLOGY OF THE YANGTZE GORGE DAMSITES, HUPEH PROVINCE, CHINA

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Sites for Yangtze Gorge Dam are located in the Ichang Gorge, lowermost of the Yangtze Gorges, 1000 miles upriver from Shanghai and 350 miles below Chungking.

The proposed dam would be a concrete gravity type, about 800 feet high. Two subsurface power plants would have an ultimate rated capacity of 15,225,000 KVA. An estimated 10,000,000 acres of land would benefit by a constant source of irrigation water. The treacherous rapids of the Yangtze above Ichang would be flooded, and a lake over 400 miles long would provide still-water navigation to China's interior and flood control for the lower valley.

The Ichang gorge is 10 miles in length. Running almost straight east and west, it cuts through a mountain range of eastward-tilted sedimentary formations which are a part of the eastern limb of a north-south anticline. Generally, the beds dip 5°–20° east or downstream. The rocks are limestones, shales, and dolomites of pre-Cambrian, Cambrian, and Ordovician age. A preliminary examination of three damsites indicates that it is geologically feasible to build a dam at any of the locations. The rock formations are structurally sound and capable of supporting the proposed dam. Large underground workings can be excavated with little or no timbering. Some of the limestone and dolomite formations contain solution channels. Geologically, the damsites are superior in the order they are numbered. But the number three site at the outlet of the gorge has excellent foundation rock and, topographically, is far superior to the other locations. The results of the geological studies are described, together with supplementary geological maps and sections.

BOLARIAN SERIES OF THE ORDOVICIAN

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The Bolarian Series (new, Bolar Valley, Virginia) comprises rocks younger than Lincolnshire, about late Chazyan, and older than Nealmont, early Trentonian, in the Virginias and Pennsylvania, and time equivalents. The Black River group of New York and Ontario is Bolarian.

Along the Appalachian Structural Front, the lower Bolarian (Hatterian) in the Virginias comprises

Ward Cove, Peery, and Benbolt limestones, and in Pennsylvania, Eyer, Grazier, and Hostler limestones. The group thins principally by convergence and overlap in the Ward Cove from about 500 feet at the James River to about 150 feet along the upper Potomac, and by continued overlap of Eyer (upper Wardcovian) by Grazier to less than 100 feet at the Susquehanna. Diminishing Lincolnshire is subjacent in the Virginias, but is overlapped in Pennsylvania. The upper Bolarian (Hunterian, new, Hunter Park, Pennsylvania) comprises Snyder, Stover, and Curtin limestones, about 300 feet at Bellefonte, Pennsylvania, thinning by truncation to about 60 feet, predominantly Snyder, near Maryland, and to about 30 feet of Snyder at the James. The thickening Gratton, Bowen, Wardell, and basal Witten take the place of the Snyder west of New River, and the Witten type section in Tazwell County seems to contain the Stover-Nealmont disconformity within the "*Camarocladia* Zone."

In New York and Ontario, the Pamelia is thought to be a facies of the higher Hatterian, and the Lowville and Chaumont to be Hunterian, Snyder, and Stover. A restored section from the New River to the Ottawa shows the relations of the beds.

BASIC INTRUSIVES IN THE CHATUGE RESERVOIR IN NORTH CAROLINA AND GEORGIA

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Underlying portions of the Chatuge Reservoir in western North Carolina and northern Georgia is a series of basic and ultra-basic rocks (dunite, troctolite, harzburgite, pyroxenite, amphibolite, eclogite, and basic pegmatite) intruded into the Carolina gneiss. There are eight zones, seven of which show a marked zonal concentricity of the various basic rock types. The other zone evidently is of earlier origin and shows a marked divergence from the rest in all of its characteristics.

Subsequent metamorphism and hydrothermal activity have produced changes making some of the original constituents difficult to ascertain. Detailed petrographic analysis is necessary to determine positively the rock types present as megascopic appearances tend to be misleading.

There is no definite way of dating the age of these intrusions, although they are obviously post-pre-Cambrian and probably were intruded sometime during the Appalachian revolution.

GEOLOGY OF NOTTELY DAM, GEORGIA

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Tennessee Valley Authority, Knoxville, Tenn.

Nottely Dam is situated on the Nottely River in Union County, Georgia, about 2.3 miles south of the Georgia-North Carolina State line. It is a rock and earth-fill structure, 2305 feet long and 190 feet high, designed and built by the Tennessee Valley Authority.

The dam is founded on a formation designated the Carolina gneiss by LaForge and Phalen, which at the site consists of a series of interbedded quartzites and schists. Micaceous quartzite and kyanite-muscovite schist predominate, with subordinate amounts of feldspathic quartzite, altered arkose, muscovite schist, and kyanite-graphite schist. Lenses and nodules of pseudodiorite occur throughout the foundation.

The dam is built across a steeply plunging anticline. The quartzite beds are extensively jointed, and the joint pattern is controlled by the anticlinal structure. Faults of measurable displacement are not numerous at the dam site; however, there has been some movement along almost every bedding plane.

In the area the rock is deeply weathered and is covered by a mantle of residuum varying from a negligible amount in the river channel to over 100 feet in the saddle behind the left abutment.

Pre-construction investigations, carried on principally by use of diamond drills and test pits, revealed that the foundation conditions were satisfactory and the rock competent to support the proposed structure. Further geologic work, consisting of detailed foundation studies and reservoir investigations, was carried on continuously during the construction period.

MULTIPLE DIFFERENTIAL THERMAL ANALYSIS

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Considerable improvements in the equipment used for differential thermal analysis in recent years have resulted from work in various laboratories. As a consequence the method is finding a constantly broadening application.

Equipment is described which is designed to further increase the utility of thermal analysis in connection with statistical studies. Through the adoption of standard recording devices and a program controller to a multiple specimen holder it has been arranged to secure six differential thermal curves at once. With this apparatus a large number of determinations may be made in a relatively short period; as many as 24 curves are obtainable in a day.

The qualitative and quantitative applications of this equipment to a variety of minerals are shown by a considerable number of selected curves. As an illustration a differential thermal study of artificial mixtures of kaolinite with various other minerals shows the change in kaolinite percentage to be essentially independent of the chemical nature of the other components. A "calibration curve" of kaolinite peak amplitude plotted against per cent kaolinite in the sample may, therefore, be assumed valid in application to an unknown mixture containing kaolinite for rough quantitative analysis.

HYDROTHERMAL ALTERATION AT SANTA RITA, NEW MEXICO

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The large copper mine at Santa Rita, New Mexico, provides an unusual opportunity for the study of hydrothermal alteration in connection with ore deposition. A granodiorite porphyry intrusive has been subjected to various stages of hydrothermal activity. For convenience in field mapping four stages have been recognized: (1) comparatively unaltered igneous rock with lustrous feldspar phenocrysts, (2) partly altered porphyry in which the feldspars have been largely replaced but the biotite is still largely intact, (3) replaced porphyry with the biotite altered to hydromica, (4) highly sericitized and silicified porphyry in which the original textures have been largely destroyed.

Comparison of the alteration pattern with assays along certain of the benches leads to the conclusion that a parallelism in distribution exists between stage three of the alteration sequence and the ore deposition. Some ore is found in stages two and four, but the maximum deposition appears to correspond to stage three.

The form of the distribution of chalcocite around apophyses of the main intrusive suggests that some of the ore at least had hydrothermal control. Even in areas where later concentration by secondary enrichment may have prevailed earlier emplacement of hydrothermal chalcocite seems likely.

The core of the intrusive appears least altered, with more advanced hydrothermal activity on either flank. Sills intrusive into the Cretaceous rocks along the margin of the ore-bearing porphyry have been altered to varying degrees. In general, the intensity of the hydrothermal activity increases in the vicinity of known ore-bearing areas. The clay minerals appear to provide an index to the measurement of the intensity.

While much more investigation is to be desired in such a complex area, it seems worthwhile to record the applicability of co-ordinated field and laboratory work in this area. Field work has utilized highly detailed topographic surveys furnished by local mining staffs. Laboratory studies have been based upon differential thermal analysis, X-ray diffraction, optical, and chemical methods.

ASSOCIATION OF COLLOIDALITY WITH NEAR-SURFACE DISCOLORATION OF BENTONITE IN BLACK HILLS DISTRICT

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Shades of bluish gray are the predominant subsurface colors of Upper Cretaceous bentonite beds of the Black Hills district in South Dakota, Montana, and Wyoming, where material so colored is known to miners as "blue" bentonite. The familiar olive-green, cream, and drab hues of natural exposures of bentonite rarely occur under more than a few yards of cover and represent discoloration, presumably due to oxidation of small amounts of iron present in "blue" bentonite, through the agency of water seeping from the land surface into crisscross joint systems in the bentonite and soaking inward toward the centers of innumerable joint blocks. This process has in general resulted in complete discoloration of the bentonite at and close to the surface, but under a few feet of cover many blocks contain small central cores of "blue" bentonite. The proportion of "blue" to discolored material increases with depth, and, as a rule, bentonite under more than 30 or 40 feet of cover is wholly "blue." Whereas nearly all the "blue" material is regarded as deficient in colloidal properties and is consequently rejected in mining, much of the discolored material is highly colloidal, swelling bentonite and is mined for use in preparation of drilling mud and as foundry sand binder. It is suggested that the colloidality of the bentonite mined in the Black Hills district may be in some way genetically related to the near-surface discoloration.

HEMATITE BOULDERS ON IRON ISLAND, LAKE NIPISSING, ONTARIO

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In 1854 Alexander Murray examined the rocks in the region surrounding Lake Nipissing, Ontario. Iron Island, consisting of approximately 200 acres, is about the center of the lake. Murray reported much rounded, very pure hematite float on the shores of the island "of all sizes from great boulders weighing several hundred pounds to small round pebbles not bigger than marbles." It seems extraordinary that the boulders have attracted little attention during the 93 years since their discovery. With the exception, many years ago, of digging a few trenches, no effort has apparently been made to find their source; nor has any geological map been published.

The western part of the island consists of ferruginous dolomite carrying about 6.6 per cent of metallic iron. The eastern part is mainly granite. These rocks are pre-Cambrian. A chemical analysis of one of the boulders gave: metallic iron 66.89 per cent; sulphur 0.11 per cent; phosphorus 0.1 per cent; silica 9.04 per cent. The origin of the boulders is obscure, but Sir Wm. Logan (1863) suggested that they may have come from the "disintegration" of the ferruginous dolomite. Thin patches of calcareous sandstone, the base of the Paleozoic, occur here and there along the west shore of the island.

The hematite boulders are similar to those found on the shores of Steeprock Lake in Western Ontario which led to the discovery of large deposits of hematite under the water of the lake.

DRILLING ON BIKINI ATOLL, MARSHALL ISLANDS*

H. S. LADD, J. I. TRACEY, GORDON LILL, J. W. WELLS, AND W. S. COLE

During a resurvey of Bikini Atoll (Operation Crossroads) in the summer of 1947 five holes totaling 4510 feet were drilled on Bikini Island. One hole located on the seaward side of the island was drilled to 300 feet, three others on the lagoon side measured 190, 1346, and 2556 feet, and a fifth hole at the south end of the island was drilled to 117 feet. Core recovery was fair above 300 feet but very poor

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at greater depths. A total of 812 feet was cored with a recovery of 135 feet (16.6 per cent). Cuttings were collected at 5 to 10-foot intervals.

No materials other than calcareous sediments—beach rock, reef limestone, coral rubble, sand—were encountered. Below the unconsolidated surface sand beach rock was found between existing tide levels; at depths of 50–65 feet below low tide a zone of hard limestone suggests that the shallow terraces fringing the existing reef and the lagoon may be continued beneath the island; below 500–600 feet the section consists of unconsolidated or very poorly consolidated sand with a few thin streaks of firmer material. Molds of corals and mollusks were abundant at depths of 300–575 feet suggesting that this part of the section was above sea level for an appreciable time following deposition.

Preliminary studies show that late Tertiary corals and mollusks were encountered at 930 feet, and the top of the Tertiary section may be considerably higher. At a depth of 1305 feet larger Foraminifera indicate a horizon well down in the Miocene.

A total of 72 velocity determinations were made in the deepest hole at depths from 1820 to 50 feet, to aid in interpreting geophysical data obtained in 1946.

The Bikini section differs markedly from that at Funafuti in the Ellice Islands where hard dolomitic rock apparently of post-Tertiary age was found at 748 feet and continued to the bottom of the hole at 1114 feet.

A NEW GENUS OF FORAMINIFERA FROM THE UPPER CRETACEOUS

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A new genus of Foraminifera, found in the Marlbrook marl of Arkansas, is a development from the genus *Globigerinella*. The later chambers in the new form are added in pairs in contrast to the single chambers of *Globigerinella*.

YARMOUTHIAN MOLLUSCAN FAUNA OF THE GREAT PLAINS AND MISSOURI VALLEY PLEISTOCENE

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Studies of the Pliocene and Pleistocene molluscan faunas of western Kansas and adjacent Oklahoma made during the past 6 years have shown that one of the most distinctive of these occurs in association with the Pearlette volcanic ash. It consists of aquatic species trapped in water bodies in which the ash was deposited and terrestrial species washed from adjacent slopes. The fauna is now known from 20 localities, distributed from northwestern Iowa and eastern Nebraska, where the fossil-bearing deposits lie between glacial tills, to western Oklahoma and northwestern Texas. Remarkable uniformity of the faunules indicates climatic stability throughout a large area. Faunal differences seem to reflect minor regional differences in climate. The fauna consists of approximately 50 species; 9 are restricted to, and 20 make their first appearance in, the Pearlette ash faunal zone. As a whole, the fauna is judged to establish the contemporaneity of the fossil-bearing beds. This is confirmed by regional stratigraphic and petrographic studies of the ash, which were made by others during the summer of 1947 in conjunction with the studies of the fauna. In the Missouri Valley the Pearlette molluscan zone occurs above Kansas till and below Loveland loess and Iowa till, which establishes the Yarmouthian age of the fauna.

LEDUC OIL FIELD, ALBERTA

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The Leduc oil field is located approximately 16 miles southwest of Edmonton, Alberta, on southwesterly dipping beds of the Alberta syncline. The field has two productive horizons in rocks of

Devonian age, consisting of dolomite and coral-reef limestone, separated from one another by 138 feet of green shale.

The discovery well was located on the basis of a seismic-reflection survey, plus the geologic knowledge of the probable presence of porous reservoir dolomite and source rock within the Devonian. The initial test encountered production in a porous dolomite containing considerable coral and other invertebrate fossil remains 605 feet below the unconformable Cretaceous-Devonian contact. The second test, located $1\frac{1}{4}$ miles down-dip from the first, developed no commercial production from the discovery horizon, but deeper drilling, based primarily upon geologic optimism, revealed the presence of a coral-reef limestone 138 feet below the base of the discovery horizon. This coral-reef zone is the main producing horizon. The field is a combination of structure and stratigraphic-trap accumulation.

Total daily production as of October 1, 1947, is approximately 1500 bbls. from 12 wells, of which 4 are from the "discovery zone," and 8 from the "coral-reef" reservoir. One well is a gas producer from the Viking sand of the Upper Cretaceous. Six failures have been drilled to date in the Leduc area. By the end of 1947 there should be 22 producing wells with a production of about 3500 bbls. per day.

BROWNSPORT AND RELATED BRYOZOA

ALFRED. R. LOEBLICH, JR.

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This project embodies the study and description of bryozoan faunules from the Silurian Waldron, Dixon, Brownsport (Beech River, Bob, and Lobelville formations), and from the overlying Devonian Birdsong formation, from the Henryhouse (Silurian) and Haragan (Devonian) of Oklahoma and the Bainbridge formation (Silurian) and Bailey (Devonian) of Missouri. Correlations of the three areas are developed on the basis of bryozoan evidence.

Brownsport, Henryhouse, and Bainbridge Bryozoa are at present undescribed bryozoan faunules. The Devonian Haragan and Birdsong formations differ much in character of bryozoan fauna, differ from their New York counterparts, and are at present undescribed. In addition to the description of these faunules, the genotype species of many Silurian and Helderbergian Bryozoa are refigured and described. As many of these were described solely on the basis of surface features, the present description of their interior structures, as based upon thin sections, will not only define them more precisely, but in some cases will completely modify the present conception of the genera.

These bryozoan faunules are numerically dominated by the orders Cyclostomata, Cryptostomata, Trepostomata, and Ctenostomata, in that order. The description of these Niagaran and Helderbergian bryozoan faunules is important in filling one of the gaps in knowledge of American Paleozoic Bryozoa.

STORM KING GRANITE AT BEAR MOUNTAIN, NEW YORK

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The Storm King granite at Bear Mountain, New York, occupies the core of a syncline in the earlier crystalline complex of the Hudson Highlands. It is part of a larger synclinal pluton whose concordance with the northeast-plunging structure is shown by conformable relations of contacts and parallel mineral alignment in both the granite and the country rocks.

Uniform composition, flow structures of early hornblende crystals, and inclusions confined to the marginal portions of the granite indicate magmatic intrusion. Absence of secondary foliation and lack of tectonic fabric patterns in the granite suggest essentially post-tectonic emplacement. The concept of "exchange of space" between the rising magma and the country rocks subsiding into the emptying magmatic chamber is proposed to account for the lack of evidence indicating lifting of the overlying rocks by forcible injection of the granite.

In contrast to most fusion tectonites described in the literature, quartz c-axes do not have clearly preferred orientations. Anomalous relations between dimensional and lattice orientation of the larger quartz grains are tentatively explained by differential solution of quartz by hydrothermal end-stage products of magmatic (Storm King granite) origin.

Field and statistical studies of principal joint systems reveal significant concentrations of longitudinal, cross, and diagonal fractures. Joint patterns in the Storm King granite and in the Highlands Complex are nearly identical. Several possible mechanisms are discussed to explain their development.

The tectonic history of the region is traced. Interpretation of faults in conjunction with other structural data is used to distinguish between the effects of pre-Cambrian and Paleozoic deformation intervals.

OXIDATION AND REDUCTION IN GEOCHEMISTRY

BRIAN MASON

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The concept of oxidation-reduction potentials is capable of wide application in the study of geochemistry and mineral paragenesis. Many elements occur in different oxidation states in the earth's crust, and oxidation-reduction potentials give a quantitative expression for the conditions of stability of these different oxidation states. Reactions involving oxidation and reduction are particularly important in the formation of minerals from aqueous solutions at or near the earth's surface. The ground-water table often forms a sharp boundary between an upper zone of high oxidation potential and an underlying zone of relatively low oxidation potential.

The significance of oxidation-reduction potentials in geochemistry is particularly marked in the way in which rare elements are often concentrated and enriched in deposits formed under extreme oxidizing or reducing conditions.

CUSPIDINE IN THE SYSTEM $CaO \cdot SiO_2 \cdot CaF_2$

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The reported occurrence of cuspidine ($Ca_4Si_2O_7F_2$) in but three localities, two of which are in volcanic areas, would indicate it to be a rare mineral. Cuspidine, however, has been identified in basic open hearth steel slags and in finishing slags from electric steel furnaces. In electric furnace slags, it is associated with larnite, merwinite, or with pseudo-wollastonite.

To determine the equilibrium relations of cuspidine 10-gram samples covering a wide range in composition of CaO, SiO_2, and CaF_2 were melted in platinum and in graphite crucibles. Cuspidine formed readily in these melts, being associated with the same minerals as in the slags. The actual mineral composition did not agree, however, with calculated compositions based on a simple chemical reaction between the three components but indicated a loss in silica.

Melts made from pulverized quartz and fluorite in graphite crucibles yielded well-crystallized cuspidine. The graphite crucibles in the muffle furnace were surrounded by a thick matt of fibrous silica which in some cases covered the crucible and the lid. The loss in weight of the original constituents was determined, and from the identification of the resultant phase this reaction follows:

$$8CaF_2 + 7SiO_2 = 2(Ca_4Si_2O_7F_2) + 3SiF_4$$

The deposit of silica surrounding the crucible is caused by the reaction of the SiF_4 with the water vapor in the products of combustion.

Attempts to determine the melting point of pure cuspidine in a quenching furnace were unsuccessful; the cuspidine was converted to a mixture of dicalcium silicate and lime and sometimes tricalcium silicate.

The reaction

$$2(Ca_4Si_3O_7F_2) \rightarrow 3Ca_2SiO_4 + 2CaO + SiF_4$$

accounts for this phenomenon. Further evidence for this reaction lies in the abundant presence of gas bubbles imbedded within the dicalcium silicate crystal fragments.

The volatilization of silicon tetrafluoride accounts for the anomalous results obtained in a previous investigation.

MINERAL ISOGRADS IN SOUTHEASTERN PENNSYLVANIA

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The formations grouped as the "Glenarm Series" consist of phyllites, schists, and gneisses with subordinate amounts of quartzite and marble. Within this series, a general, though by no means regular, increase in intensity of metamorphism toward the east and south has long been recognized; several authors have published small-scale maps, some based on texture and some on mineral distribution but without definite mineral isograds.

The main feature of the present paper is a map of the area covered by the Philadelphia and Coatesville-West Chester folios showing reported and observed occurrences of diagnostic minerals. In the argillaceous rocks the zonal arrangement: chlorite, biotite, garnet, staurolite, cyanite, sillimanite accords with observations in metamorphic areas in other parts of the world. The zones are somewhat crowded and show local overlapping. In the associated carbonate rocks, tremolite appears in the middle-grade zone, and sparse pyroxene in the highest grade attained. Wollastonite and garnet have not been reported in the carbonate rocks.

TRIASSIC AMMONOID GENUS PARATRACHYCERAS

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When establishing the genus *Paratrachyceras* Arthaber published a long list of species which he referred to it. Of these only four seem close enough to the genotype *Paratrachyceras hofmanni* Boeckh to be retained in it, namely *P. richthofeni* Mojsisovics, *P. regoledanum* Mojsisovics, *P. mundevillae* Mojsisovics, and *P. dichotomum* Muenster. To these may be added *P. laczkoi* Dienere. The early Karnian species are somewhat more involute than the late Ladinian species and have ammonitic to subammonitic suture lines. All have numerous, curved, projected ribs which end in single tubercles or "swellings" on the border of the ventral sulcus.

The remaining species in Arthaber's original list should be retained in *Protrachyceras* or placed in new genera.

TRIASSIC AMMONOID GENUS PROTRACHYCERAS

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Species now included in *Protrachyceras* Mojsisovics exhibit a wide range in ornament and form. This range should be carefully studied before any generic revision is attempted. It is recommended that the genus be not too restricted.

Many Anisian to late Ladinian species like *P. dunni* have moderately evolute to moderately involute, variably compressed shells with several lateral rows of unmodified tubercles, unmodified ventral tubercles, and curved ribs. The ventral tubercles are modified to clavi parallel to ventral sulcus in some late Ladinian and early Karnian species like *P. aeoli*. The lateral tubercles are modified to fine bullae at maturity in some late Ladinian to early Karnian species. All tubercles become spinate in some late Ladinian and early Karnian species. Mixed lateral tubercles and spines appear in some early Karnian species like *P. atavum*. Lateral clavi on broad ribs appear in some early Karnian species like *P. hadwigae*. Fewer than usual number of rows of tubercles appear in several separate groups of species from early Ladinian to late Karnian; many of these species groups appear to be independent offshoots of *dunni*-like species by reduction in rows of tubercles at maturity. A fine strigate ornament, with involution of shell, appears in some late Karnian species from California.

The shell form of the late Ladinian *P. spitiense* recalls that of Anisian *Nevadites*.

The suture line is ceratitic to ammonitic from Anisian to Ladinian and possibly ammonitic only in the Karnian.

INFLUENCE OF JOINTING ON THE EROSION OF LOST RIVER AND FLUME GORGES, NEW HAMPSHIRE

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Lost River in Kinsman Notch and the Flume in Franconia Notch are major tourist attractions in the White Mountains. Closely spaced joints in massive igneous rocks appear to have had a major influence in the erosion of both gorges.

Lost River gorge was eroded by sediment-laden glacial meltwater which poured southward through Kinsman Notch. In the vicinity of the present gorge irregularly spaced, southward-dipping joints in Kinsman quartz-monzonite gneiss localized scour to produce a small steep-walled gorge which had irregular water-carved sides. Most of the meltwater was derived from glacial ice north of Kinsman Notch. As the ice surface melted down it uncovered lower outlets north of the notch, and as a result the only water left to go through the gorge was the small brook which flows through it today. Frost action, during and immediately following the melting of the ice sheet, widened the southward-dipping joints and forced blocks to fall into the gorge from its north wall. These blocks accumulated as a chaotic jumble in the bottom of the gorge.

The Flume was eroded during postglacial time in Conway granite that had been broken by closely spaced vertical joints. Four diabase dikes arranged *en echelon* were emplaced along the joints. A fifth dike, oblique to the others, was intruded along a relatively gently dipping joint set. Preglacial erosion produced a broad valley at the site of the present gorge as shown by the attitude of almost horizontal sheet joints in the walls of the gorge. The granite, cut by the narrow zone of vertical joints, and by closely spaced sheet joints, restricted gorge cutting laterally so that a narrow almost vertically sided valley was formed.

CHARTING FIVE, SIX, AND SEVEN VARIABLES ON HYPERTETRAHEDRAL FACES

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Three variables may be charted in a triangle by the use of trilinear co-ordinates, and four variables in a tetrahedron by means of quadrilinear co-ordinates. This unique property of the triangle and tetrahedron suggests that a similar property exists for hypertetrahedra of *n* dimensions.

By mathematical induction, it is possible to predict the number of vertices, edges, triangular faces, tetrahedra, and hypertetrahedra that bound an *n*-dimensional hypertetrahedron. A tabulation of these boundaries, up to the ninth dimension, is given. The number of vertices in each hypertetrahedron corresponds to the number of variables that may be charted within it. Hypertetrahedra of 4, 5, and 6 dimensions, having 5, 6, and 7 vertices, are bounded respectively by 10, 20, and 35 triangular faces.

Two methods exist for charting four variables in a tetrahedron. From a number of sets, a surface may be geometrically constructed or analytically deduced; and a topographic map of this surface may be drawn. A second method is to develop the tetrahedron onto a plane, and merely to plot the triads 123, 124, 134, and 234, each recomputed to 100 per cent. The first method is inapplicable to hypertetrahedra, and the second method may not be exactly applied, as hypertetrahedra cannot be developed. The triangles bounding the hypertetrahedra, however, may be arranged empirically so as to constitute a compound system of trilinear co-ordinates for charting the triads 1, 2 . . . (v-l), 3 . . . v, 2,3 . . . . (v-l), 4 . . . . v, 3,4 . . . . (v-l), 5 . . . v, etc., where v means both vertices and variables.

Co-ordinate systems of this kind have been prepared for charting 5, 6, and 7 variables. Some choice exists in the arrangement of the triangles, but compactness and the preservation of developed tetrahedra are determing factors that practically eliminate alternative arrangements. Such co-ordinates may be given algebraic meanings within triangles, but not between them. Composite charts, however, afford geometrical pictures, which, if conventionalized, may be as effective as a true system of analytical co-ordinates.

FUSION OF SANDSTONE BY INTRUSIVE ANDESITE, PALISADES DAMSITE, IDAHO

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During pre-construction investigations at Palisades Damsite, on the Snake River, about 44 miles east of Idaho Falls, Idaho, an irregular sill-like body of hypersthene-augite andesite intrusive into sandstones, siltstones, and claystones at the left abutment has been explored extensively. The andesite is basic (57.9 per cent SiO_2), contains microphenocrysts of hypersthene, augite, and labradorite in a groundmass of microcrystalline labradorite, augite, and magnetite with interstitial glass. Secondary clay minerals ranging from montmorillonite to nontronite occur in the groundmass, having formed from the primary minerals and glass, and in voids and fractures. Calcite veins 1½ inches wide are present. Well-developed crystals of tridymite, possibly the variety christensenite, occur in voids and apparently formed prior to associated nontronite.

As indicated by drill cores, the andesite-sediment contact is irregular; it varies from highly contorted to relatively plane and typically transgresses stratification. In several places, sandstones at the contact have been partially fused and caused to flow. Particles of sediments enclosed by andesite are partially digested and surrounded by reaction products. In one occurrence volcanic glass penetrates sandstone more than 1 inch. Locally the sediments are affected through an 8-foot-wide zone.

The partially fused sandstones are gray, vesicular, massive to flow-banded, and very hard. In one occurrence, the fused material is intruded upwardly into adjacent indurated sediments. Microscopically, the grains of sand are observed in an isotropic or cryptocrystalline matrix; minute prisms of secondary pyroxene are present. Vesicles are ellipsoidal, up to 3.0 mm. in diameter, and are lined or partially filled with tridymite.

INVESTIGATION OF FREEZING AND THAWING DURABILITY OF ROCK MATERIALS

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The ability of rock and concrete to withstand the effects of freezing and thawing of water is important to the serviceability of engineering structures. Therefore, durability of materials should be established before they are used. At present, the most reliable determinations involve accelerated freezing and thawing of selected specimens, but the procedures are time-consuming and require elaborate equipment. Consequently, the Bureau of Reclamation has undertaken research to discover the causes of low durability and to devise new techniques for measuring durability.

Although the mechanism of freezing and thawing breakdown is not understood fully, experience indicates that low durability relates to abundance of small, continuous, internal voids. Therefore, an index to durability can be obtained by measuring the rate of evaporation from saturated specimens and the force associated with capillary movement of water into the material.

Newly designed apparatus comprises a clamp to hold the specimen (a 1½- by 1-inch cylinder), a reservoir of water against its upper surface, and a mercury manometer affixed to the reservoir. Abundance of continuous passageways is indicated qualitatively by rate of evaporation (pressure decline), and the minimum diameter of the largest continuous passageway is calculable from the pressure ultimately developed in the reservoir. The test can be completed in 1 to 6 hours.

Unsound rocks cause rapid pressure decreases in excess of 22 inches of mercury; unsound concretes cause rapid decrease of 20.7 inches or more. These investigations indicate that pores critical to reduction in freezing and thawing durability are less than 0.004 mm. in size.

CHEMICAL TEST FOR REACTIVITY OF CONCRETE AGGREGATES WITH CEMENT ALKALIES

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Deleterious reactivity of aggregates with high-alkali cements can be predicted from results of a chemical test developed by petrologic research. Deleteriousness is determined from the amount of silica dissolved by 25 milliliters of 1-normal sodium hydroxide solution during 24 hours at 80°C from a 25-gram sample crushed to the No. 50 to No. 100 size, and the concomitant reduction in the alkalinity of the solution. The sample can be prepared, the test made, and the necessary analyses completed during 3 work days; if several samples are tested simultaneously, each determination involves about 6 man hours.

The test has indicated correctly the deleterious or innocuous character of 75 minerals, rocks, sands, and gravels for which mortar-bar data and many service histories are available. Aggregates causing large, long-continued mortar expansion characteristically release large amounts of silica into solution but cause only small reduction in alkalinity. Aggregates causing large and rapid, but not long-continued mortar expansion characteristically release large amounts of silica and cause large alkalinity reduction. Innocuous aggregates are indicated in the test by small silica release and small to large alkalinity reduction, or by moderate silica release and large alkalinity reduction. For the minerals, rocks, sands, and gravels tested, the concentration of silica in solution at completion of the test ranges from 2.3 to 1100 millimoles (0.14 to 66 grams) per liter or from 0.01 to 6.60 per cent by weight of the sample used. The reduction in alkalinity ranges from 12 to 500 millimoles of titratable hydroxyl ion per liter.

AMERICAN PERMIAN NAUTILOIDS

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Nautiloids are not rare in the marine Permian of the United States, and locally they are abundant. A few specimens are known from Canada, Mexico, and Colombia. Only two types of conch, orthoceraconic and nautiliconic, are represented. None of the straight forms bear prominent ornamentation, but ribs, nodes, and spines are present on some of the coiled ones.

Certain of the species, and even a few of the genera are more or less gradational. Nevertheless, 19 genera can be recognized. Five of these include only straight forms, and the others are composed exclusively of nautilicones. All are referable to seven families.

UPPER ORDOVICIAN CEPHALOPOD FAUNA OF SOUTHEASTERN BAFFIN ISLAND

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During the summer of 1947, we collected a variety of well-preserved cephalopods and associated marine invertebrates on Silliman's Fossil Mount at the head of Frobisher Bay near the mouth of the Jordan River. These confirm the Upper Ordovician age of the containing beds and indicate that they are the approximate correlative of the Cape Calhoun beds of northern Greenland, the Red River formation of southern Manitoba, the Bighorn formation of Wyoming, and probably the Whitewater formation of Ohio and Indiana.

A second limestone outlier was discovered just west of the Jordan River and about 13 miles above its mouth. It is considerably larger than Silliman's Fossil Mount and is divided into two unequal parts by a tributary of the Jordan. The larger portion of this mount lies between the Jordan and the tributary, and it is several miles in length.

GEOTHERMAL MEASUREMENTS IN THE CANADIAN SHIELD

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To obtain a complete geothermal picture of part of the Canadian Shield lying between Kirkland Lake and Timmins, Ontario, measurements of temperature gradients, thermal conductivity, specific heat, and density are required. Temperature gradients were determined from rock temperatures measured to 0.02°C at 33 underground positions in mines with wide distribution both laterally and vertically to 7000 feet. The other constants are determined by laboratory measurements on specimens taken from these positions and from surface specimens characteristic of the district. The average heat flow at the surface is calculated, and certain anomalies in the temperature gradients are discussed.

"BLOWING" CAVES IN EASTERN TENNESSEE

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Many of the caves developed in tilted strata in eastern Tennessee are called "blowing" caves because currents of air issue from their openings. Actually, the same openings that "blow" in one season "suck" in another.

The "blowing" and "sucking" phenomena exhibited by a cave are caused by the free circulation of air through underground passages in response to differences in air temperatures within and without. In the cold seasons, when the cave air is warmer than that outside, the former is expelled through the higher openings to the surface by cold outside air which crowds into the cave at lower openings. In the warm seasons, when the cave air is cooler than that outside, the former moves out through lower openings and is replaced by warmer air which enters through higher openings. Thus, in the cold season, the cave "blows" at the higher openings and "sucks" at the lower openings, and in the warm season, it "blows" at the lower openings and "sucks" at the higher openings.

In order for a cave to exhibit "blowing" and "sucking" phenomena, it must have spacious and extensive underground passages with openings to the surface at both high and low levels. There must be a difference in the temperature of the air inside and outside the cave.

Although the temperature of cave air tends to be constant at 54°–56°, it may be somewhat cooler or warmer as a result of contamination by air from the outside. As soon as the temperature of the outside air equals that of the cave air, the "blowing" and "sucking" behavior ceases.

GEOLOGIC CONDITIONS AT FONTANA DAM

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Fontana Dam, the highest dam in eastern United States, is located on Little Tennessee River in Graham and Swain counties, North Carolina. It is a concrete gravity structure, 480 feet high, 2365 feet long at the crest, and 377 feet wide at the base.

The entire structure is founded on the Great Smoky formation (pre-Cambrian), which consists exclusively of massively bedded, fine to conglomeratic, bluish-gray, impure quartzite and dark, faintly banded phyllite. These rocks are intimately interstratified. As a result of folding and faulting, the strata are steeply tilted, and have northeast strikes and southeast dips. The right abutment is a dip slope, made up nearly entirely of quartzite which dips 40°–50°; the left is a scarp slope, made up of about equal amounts of quartzite and slate, which dip 51°. There are no faults of serious importance in the dam site, but a few shear zones in the quartzite are marked by closely fractured rock which is weathered to depths as great as 400 feet. Joints of several types are numerous in both quartzite and slate, and some of them are quite extensive, laterally and vertically.

The most serious geologic problem at Fontana Dam is the overburden. Except in the river channel, bedrock was concealed by a residual mantle ranging from a few feet to a maximum of about 70 feet. The bedrock below this mantle was very deeply weathered, necessitating heavy excavation in places. The downstream dip of the strata in the lower portions of the left abutment, and the presence of weathered material and thin layers of soft schist between quartzite beds, required special precautionary measures.

GEOLOGY OF DOS BOCAS DAM, PUERTO RICO

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Dos Bocas Dam is located on the Arecibo River immediately downstream from its junction with the Caonillas River. It is a concrete, gravity-type dam, with a maximum height of 185 feet and a length of 1115 feet along the crest.

The dam is founded on massive tuff and agglomerate of Cretaceous age and andesitic composition. Except for a few very thin layers of stratified volcanic ash, the rock is entirely without primary depositional structures. The rock is unfaulted but is cut by numerous joints, most of which are mineralized.

Three sites, located within a section of the river 1½ miles long and appearing to be about equal geologically and topographically, were explored by core borings and test pits. This exploration proved that the sites were almost identical, except that the gravel and boulder overburden in the stream channel increased from about 15 feet at the upper site to 35 feet at the middle site and more than 40 feet at the lower site. The upper site was selected as the most feasible site.

The only geologic conditions resulting in engineering problems were the thickness of the residual overburden and great volume of unsound rock, especially in the abutments. In the preparation of the foundation, all undesirable material was removed. Some of the rock left in the foundation is weathered, but it is sufficiently strong, solid, and tight to afford a good satisfactory foundation. The left end of the dam abuts against a bedding plane which is steeply inclined downstream.

GEOLOGY OF GARZAS DAM, PUERTO RICO

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Garzas Dam, located on the Vacas (Garzas) River in the upper portion of the Arecibo drainage basin, is a rolled fill earth dam, 195 feet high and 835 feet long with heavy rock blankets and toes.

The foundation rock at Garzas consists mainly of extrusive rocks, especially tuff and agglomerate and flows of amygdaloidal andesite. These rocks are cut by dikes of andesite porphyry. Faults of undetermined displacement are numerous in the immediate vicinity of the dam; the nearest one is 200 feet upstream from the center line. As a result of faulting, the strike and dip of the stratiform rock masses (flows and tuff layers) vary within very wide limits.

Bedrock was exposed in the river channel and in numerous outcrops up to near pool level in both abutments. On the whole, the overburden was thin at the dam site but was quite thick immediately back of the right abutment. The right abutment is formed by a linear, narrow-crested spur which trends normal to the river. The rocky terminus of this spur is the riverward face of a pyramidal pinnacle of rock, separated from the main rock mass of the adjacent highland by a narrow ridge of residual earth.

For a dam of the type designed for the Garzas site, the geologic conditions presented no problems.

GEOLOGY OF THE GARZAS POWER TUNNEL, PUERTO RICO

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Water from the Garzas reservoir on the north side of the Insular Divide in Puerto Rico is diverted by tunnel southward through the Insular Divide. The tunnel is 11,674 feet long and is a 7-foot horseshoe in cross section. It crosses the main structural features of the Cordillera Central at a high angle. In the northern 10,486 feet of its length, the bore penetrates water-laid volcanic ash shales and associated limestones; the remaining 1188-foot section penetrates very hard massive tuff and agglomerate of andesitic character. All of these rocks are cut by dikes of andesite porphyry.

Hundreds of faults were encountered, but most of them were small and presented no problems. Many of them were marked by shear zones and occasioned appreciable overbreakage. For support, these structures required timbering during construction and lining afterward. Two major faults, both apparently active, were crossed with some difficulty and after considerable delay. Both yielded copious quantities of water under considerable head. One of them resulted in the caving of the heading and the partial filling of the bore with 1000 cubic yards of fine gouge and 500 cubic yards of broken rock. This fault zone was 152 feet wide and yielded 1300 gallons of water per minute. The other fault also resulted in the failure of the heading and the partial filling of about 40 feet of the bore with broken rock and gouge. The fault zone was only 21 feet wide and yielded 200 gallons per minute of water under a head of 160 pounds per square inch.

RELATION OF MINOR INTRUSIVES TO GRANITE IN THE BRYCE AREA, ONTARIO

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A petrographic and chemical study is presented of sodic porphyries, lamprophyres, and granitic rocks in the vicinity of Bryce township, Ontario. It is concluded that the minor intrusives crystallized from a late extract of the granite batholith, modified by reaction with the country rock. This conclusion is supported by field evidence and by the textures, chemistry, and mineralogy of the rocks involved. An attempt is made to correlate these results with the intrusives of the Kirkland Lake area which lies on the north side of the granite batholith in question.

GEOLOGY IN CONCRETE AGGREGATE TECHNOLOGY

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Specific instances of concrete disintegration attributable to natural aggregates have directed the attention of leading engineers and aggregate producers to geological methods which may be utilized as a supplement to standard laboratory acceptance tests. These latter, which include tests for chemical composition, specific gravity, absorption, coefficients of expansion, sulphate soundness, resistance to freezing and thawing, and abrasion loss, have demonstrated limited reliability in view of subsequent poor concrete performance records. While chemical analyses of various natural and processed aggregates are significant in predicting their behavior, only by subjecting potential sources to careful geologic investigation can behavior prediction be made with any degree of reliability.

Geological investigations are directed (1) toward developing general information on the distribution, structure, and association of the major aggregate producing horizons, and (2) toward obtaining complete microscopic data on the petrologic, textural, and structural aspects which influence the

durability and serviceability of a given rock, gravel, or sand. Chief among the features which receive close scrutiny under the microscope are mineral composition, surface texture, surface coatings, intracrystalline texture, and fractures. While emphasizing the inadequacy of conventional aggregate tests to evaluate such features in terms of subsequent performance, it is pointed out that the geologist and engineer should not overlook the far more frequent causes of concrete failure such as unsound cement, extreme temperature variations, excess water, faulty curing, faulty washing, overstressing, and the like.

PERMIAN PELECYPODA FROM THE SOUTHWESTERN UNITED STATES

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One of the most important assemblages of Paleozoic pelecypods ever discovered occurs in the silicified Permian faunas of the West Texas region. The exhaustive collecting and acid preparation of these faunas, begun by Cooper at the National Museum, and continued as a co-operative project with several institutions have resulted in an accumulation of one of the most remarkable collections of fossil invertebrates ever assembled. Pelecypods are relatively less abundant than some other groups. Nevertheless, by means of exceptionally large-scale collecting methods at least 10,000 pelecypod valves have been assembled for study. Perhaps 100 species are represented by sufficient quantities of specimens to permit simple quantitative analysis. About 50 genera are represented, nearly half of the total number of valid marine genera thus far correctly reported from the Permian. New data on the majority of genera permit the formulation of more complete diagnoses.

PENNSYLVANIAN AND PERMIAN OF PERU

NORMAN D. NEWELL, B. JOHN CHRONIC, JR., AND THOMAS G. ROBERTS

An expedition, sponsored jointly by the American Museum of Natural History, Columbia University, and the Instituto Geológico del Perú, devoted the 1947 field season to a detailed examination of selected Late Paleozoic sequences in various parts of Peru. A number of sections were measured, some of them more than 15,000 feet in thickness, and nearly 2 tons of well-preserved fossils were collected. These include mainly fusulines, Bryozoa, and silicified Brachiopoda. The faunal facies is closely similar to that of equivalent strata in the mid-Continent region of the United States.

ZONED METASOMATIC GNEISSES RELATED TO STRUCTURE AND TEMPERATURE, LARAMIE RANGE, WYOMING*

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During geologic work in the Laramie Range, southeastern Wyoming, from 1945 to 1947, an area of pre-Cambrian metasomatic gneisses was mapped in detail. The gneisses, which are dioritic to granitic, replace metagabbro schist. A zonal variation of gneisses occurs along strike, with highest-temperature facies in the most open structure and lowest in the tightest structure. This is indicated by percentage variations of plagioclase, anorthite content, potash feldspar, pyroxene, and biotite. Abrupt lithologic variations across strike reflect time intervals of shearing. Mineral zoning and relation to structure are analogous to these features in ore deposits.

Migration of K and other ions upward and laterally by diffusion through liquid in shear fractures, or by surface diffusion along planar structures and in the solid state, drove out Mg, Fe, and other elements from metagabbro schist. Numerous cordierite bodies formed by advancing metasomatism in metagabbro schist. Under certain conditions of similar metasomatism minor elements such as Zn, Pb, and other metals in host rock silicates should be prohibited in part from entering the crystal

* Published by permission of the Director, Geological Survey, U. S. Department of the Interior, and the State Geologist of Wyoming.

lattice of newly formed silicates and move upward to form ore deposits. None is present here possibly because of high temperature, kind of silicates, and rapidity of crystal formation. Pegmatites, other than occasional small granites, are lacking—an absence related to the high thermal gradient.

Metasomatic gneisses which replace hornblende schist 25 miles northwest contain more potassic facies on more open parts of the structure; tighter portions have facies higher in lime and soda.

The first example of zoning formed against relatively cool, the second against relatively hot, host rock.

ELEVATED BEACHES OF MARGUERITE BAY, ANTARCTICA

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An excellently developed and well-preserved elevated beach covers a large part of Stonington Island. On near-by Neny Island there is also an extensive elevated beach. These beaches indicate that the marine limit in this area is approximately 80 feet.

On the upper part of these beaches many of the roundstones of basic composition are fretted. The individual pits are numerous, well developed and commonly more than an inch deep. They probably owe their origin to exudation as salty snow is blown by the bay ice into the beaches. The acidic coarse-grained roundstones on the older parts of the beaches are commonly roughened by exfoliation, and accumulations of spalled fragments often surround them.

Talus cones are found on Neny Island which are progressively burying the beach. A small alluvial fan also buries part of it. On Stonington Island portions of the beach are covered by snowdrift ice slabs which have increased in size as the beach was progressively uplifted.

These beaches have not been overrun by readvancing glacial ice. They prove that shelf ice has not been present immediately offshore since their inception. The net recession of the northeast piedmont glacier, during the formation of the Stonington Island raised beach, has been surprisingly small as the glacier is only a quarter of a mile from it.

An ancient strand line which rises 26 feet above sea level was observed by Charcot on Jenny Island. Elevated beaches, in the northern part of Marguerite Bay, 70 feet above sea level, have been described by Fleming.

GEOLOGY OF STONINGTON ISLAND AREA, MARGUERITE BAY, ANTARCTICA

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A simplified and tentative geologic history of the area in the vicinity of Stonington Island, Marguerite Bay, Antarctica, follows: (1) The oldest rock is a gneiss. It is commonly pinkish, in places excellently banded, and the igneous parts of it contain inclusions. (2) The country rock of Stonington Island is a coarse-grained massive acidic igneous rock. It contains several kinds of inclusions and it has been invaded by many different kinds of dikes. (3) The most conspicuous dikes on Stonington Island are gray black. They have emplaced themselves in part by stoping. (4) Gray granite dikes. (5) Pink pegmatitic and pink granitic dikes. (6) These rocks have been slightly pyritized, and areas heavily stained with limonite are common. (7) Basaltic dikes. (8) Epidote veins. (9) The central part of the Palmer Peninsula is a plateau which east of Stonington Island has an average height of 5000 to 6000 feet and a relief of many hundreds of feet. According to Knowles it is composed of massive igneous rocks, and it seems likely that it is an uplifted erosion surface. (10) A period of erosion, subsequent to the uplift, was followed by a submergence which resulted in the drowned topography which characterizes this coast. (11) The latest movement has been upward; it amounts to 80 feet and is probably related to deglaciation.

The area is still heavily glaciated. Highland ice, snowdrift ice slabs, and valley piedmont, tide water, cliff, cirque, outlet, and fringing glaciers are common.

EXPERIMENTAL TEST OF PREDICTED ABSORPTION OF ALPHA-RAYS IN MINERALS

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In the measurement of geologic age by the helium method, the activity of the most suitable material is commonly as low as 10^{-7} gm of uranium or thorium per gram of sample, an amount too low to measure accurately by total alpha count from thin sources. Thick-source emission is enough greater to permit the utilization of this easy method in most cases. However, in thick-source counting a correction must be made for the "stopping power" of the mineral. It was desired that the Bragg-Kleeman rule, giving the approximate range and thus the absorption of the various alpha-rays from the U and Th series in different media, be checked experimentally to see if it was sufficiently accurate for this correction.

A number of pulverized mineral samples, previously analyzed for U and Th by Rn and Tn measurement, were tested for total emission from a plane surface of the powder on a source plate, the thickness of source exceeding the maximum alpha-ray range. The theoretical emission from each sample was computed from the Rn-Tn value, assuming the stopping power of the mineral was proportional to the sum of the atomic fraction times the square root of the atomic weight of the elements in the mineral. It was found that the observed emission agreed with the predicted emission within 4 per cent, over a range of mineral densities.

FRANCKEITE IN RELATION TO LENGENBACHITE

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The symmetry of franckeite was described as orthorhombic, pseudo-tetragonal (Ahlfeld, Himmel, and Kleber, 1935) on the basis of goniometric measurements on poor crystals from the Porvenir vein, Huanuni, Bolivia. Rotation and Weissenberg photographs of a crystal from this locality show monoclinic symmetry and lead to a cell with $a = 46.85$, $b = 11.62$, $c = 17.28$ kX, $\beta = 94° 48'$; cell content $16[5PbS \cdot 3SnS_2 \cdot Sb_2S_3]$.

The rotation photograph indicates the presence of a pseudo-period with $b' = b/2$. The Weissenberg resolutions of the layers (*h0l*) and (*h2l*) show well-defined spots and continuous curves with *h* a multiple of 8. Hence there is a pronounced pseudo-cell with $a' = a/8$, $b' = b/2$, $c' = c$. The films bear a striking resemblence to those obtained on lengenbachite, $6PbS \cdot (Ag,Cu)_2S \cdot 2As_2S_3$ (Nuffield, 1944), a mineral with similar habit and cleavage. Here, however, the layering is a multiple of 6. Data for the pseudo-cells of the two minerals compare as follows:

	a'	b'	c'	β	Z	G(calc.)	G(meas.)
Franckeite...............	5.86	5.81	17.28	94° 48′	1	5.87	5.88
Lengenbachite...........	5.80	5.745	18.36	94° 19′	1	5.78	5.80

Obviously these two minerals are related structurally although quite different chemically.

CONDUCTIVITY OF DILUTE WATER SOLUTIONS NEAR THE CRITICAL TEMPERATURE

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Attempts to measure the conductivity of water and solutions of low concentration through the critical temperature are described. The methods employed include tubular stainless steel bombs with electrodes introduced through insulating connectors. Various frequencies from 60 to 10,000 cycles per second have been applied. The conductivity is measured with an impedance bridge. Results to date are reported showing increasing conductivity with rising temperature in the liquid state until the critical region is approached; a much lower order of conductivity for the vapor phase but increasing also. The two curves approach each other in the critical region and appear to join in such a way as to indicate a transitional range of several degrees rather than a single critical temperature. Difficulties inherent in the method are presented, and criticism and suggestions are invited.

The investigations are being conducted as part of a research contract with the Signal Corps Engineering Laboratories, which calls for experimentation in the artificial crystallization of quartz of a size useful for piezoelectric purposes.

LATE CENOZOIC FAULTING IN WESTERN MONTANA

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Many of the mountain ranges in western Montana, and adjoining intermontane basins, are interpreted as chiefly the effects of block faulting like that in the Great Basin. The history of the region includes elevation above the sea in late Cretaceous or early Tertiary time, followed by a long period of crustal stability in which a great thickness of rocks was eroded. By Oligocene the region was reduced to a surface of moderate to slight relief, and during the Oligocene and Miocene drainage became sluggish or ponded, chiefly because of slow crustal movements that outlined the present basins and ranges. Areas corresponding approximately to the present basins became depressed, and in these the Tertiary lake beds accumulated. Areas of uplift corresponding to the present mountains were eroded and contributed land waste and volcanic ash to the lake beds. In late Miocene or early Pliocene the surface comprised areas of older rocks that, except for scattered residual peaks and ridges, had been eroded to slight or moderate relief; and areas of the lake beds that formed gently sloping or level plains. Excluding the residuals this surface is called the Late Tertiary peneplain.

Further leveling of the older rock areas and deposition of the lake beds was interrupted by reelevation accompanied by greatly accelerated local crustal movements that relatively elevated the present mountains. These movements continued intermittently and with decreasing intensity through the Pliocene and, except for small displacements as late as the recent epoch, ceased in early or middle Pleistocene. They are thought to constitute a distinct late stage of Cenozoic mountain building.

During the halt in the uplift, wide stream valleys up to 1500 feet deep were eroded in the elevated and deformed peneplain. In the basins during this pause, called the Old Valley cycle, the lake beds were reduced to gently sloping plains collectively referred to as No. 1 Bench. With resumed uplift the more vigorous streams deepened their channels across the mountain blocks as fast as the surface rose and thus excavated their narrow inner valleys or gorges. In this, the Present cycle of erosion, No. 1 Bench of the lake bed areas was, in most basins, dissected to a series of terraces. Faulting appears to be indirectly related to an axis of compression trending from Yellowstone National Park northwestward. Horizontal compressive forces moved opposite parts of a deeply buried layer of the Earth's crust toward this axis. Relief from the compression raised the overlying layer thus causing tensional strains that were relieved by normal faulting and movements away from the plane of the axis.

FELDSPAR INTRODUCTION IN THE RED RIVER DISTRICT, NEW MEXICO

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The border facies of the pre-Cambrian granite bodies in the Red River-Twining area of northern New Mexico show clearly the methods of introduction of potash feldspar into metamorphic rocks, especially into amphibole schists and gneisses. A few scattered grains of bright salmon-colored feldspar with quartz were first noted along narrow cracks, either parallel to or transverse to the foliation of the metamorphic rocks. The salmon-colored feldspar permeated the country rocks from such tiny fractures and apparently replaced the pre-existing minerals. The process became more and more intense until the resulting rock resembles a gneissic granite. The grains of the introduced feldspar range from microscopic to crystals more than 3 inches long; the average is probably about $\frac{1}{2}$ inch. Muscovite and albite feldspar are commonly introduced in small amounts with the potash feldspar, and locally black tourmaline is present. Deposition of the feldspars is thought to have taken place under a cover of several thousand feet. The potash-bearing fluids were not channeled along well-defined open fissures or faults, but rather soaked through all available openings in the metamorphic rocks. The extent of the feldspar introduction by replacement is hypothetical as evidence has been recognized only along the borders of the granite. Feldspars within the interior of the mass are, however, identical in composition and texture with those on the borders.

HEXAGONAL ZONAL EQUATIONS

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Two zonal equations are presented. The first uses Bravais indices where $p_0 = \frac{1}{3} \cdot c/a$ and $\Pi_0 = \frac{1}{3} \cdot c/\sqrt{3a}$, and $h + k + i = 0$ and $(h + 2k) + (2h + k) + (h - k) = 0$. This requires simultaneous equations involving three sets of rectangular axes.

The second uses Klein indices where $p_0 = \frac{2}{3} \cdot c/a$ and $\Pi_0 = \frac{2}{3} \cdot c/\sqrt{3a}$, and $h + k + i \neq 0$ and $(h + 2k) + (2h + k) + (h - k) \neq 0$, but $h + k + i + (h + 2k) + (2h + k) + (h + k) = 0$. This gives equations involving a vertical axis and two sets of three horizontal axes.

Both equations are heptaxial. In the gnomonic projection u/w and v/w are shown as ratios between p_0 and Π_0 and the zonal intercepts. It is impossible to use Klein axes with Bravais indices or Bravais axes with Klein indices.

TELESCOPED XENOTHERMAL MINERAL ASSOCIATION IN ALKALIC PEGMATITES AND RELATED VEINS, VERMICULITE PROSPECTS, BEARPAW MOUNTAINS, MONTANA

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Pegmatites and veins genetically related to an early Tertiary, potash-rich syenitic magma, are intrusive into fractured syenitic porphyry and fine-grained alkalic monzonite in the Rocky Boy composite stock at the site known as the Vermiculite Prospect, near the head of Big Sandy Creek, Bearpaw Mountains, Montana.

The complex mineral assortment of these deposits represents an alkalic counterpart of the quartz-rich deposits in other regions that have been called telescoped and xenothermal by Spurr, by Buddington, and by others. The pegmatites and related veins at the Vermiculite Prospect are believed to have formed at a depth of from 3000 to 5000 feet under conditions of rapid fall in temperature.

Silicate minerals include sanidine (in pegmatites) and adularia (in veins); aegirite, biotite, sphene, and zircon. Oxide minerals include magnetite, ilmenite, hematite, brookite, and perovskite. Sulfide minerals include pyrrhotite, pyrite, galena, chalcopyrite, and sphalerite. Calcite is abundant. Other minerals include apatite, chlorite, fluorite, barite, celestite, apophyllite, and analcime.

Under action of surface waters the biotite has been locally altered to vermiculite, especially in the vicinity of pyrrhotite, and in some places it has been leached of its bases to form brittle, white plates.

SCORZALITE AND SOUZALITE, TWO NEW PHOSPHATE MINERALS ASSOCIATED WITH BRAZILIANITE, MINAS GERAIS, BRAZIL

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The paper describes two new phosphate minerals associated with brazilianite from the original brazilianite-bearing pegmatite near Divino, Minas Gerais, Brazil. The new minerals are named in honor of Dr. Evarists Scorza and Dr. Antonio José Alves de Souza, both of the Departmento Nacional da Produção Mineral, Rio de Janeiro, Brazil.

Scorzalite is a massive, blue hydrous iron magnesium aluminum phosphate with the formula R_2O_3:RO:P_2O_5:H_2O; chemical analysis:Al_2O_3 = 30.87; Fe_2O_3 = 0.54; TiO_2 = 0.10; FeO = 14.74; MgO = 4.23; MnO = 0.11; P_2O_5 = 42.90; H_2O^+ = 5.86. The x-ray powder pattern of scorzalite is identical with lazulite, and the two minerals form a continuous series arbitrarily separated where the Mg-Fe molecular ratio is 1:1. Specific gravity is 3.33; biaxial (−), 2V med-large; X near 1.637; Y near 1.663; Z near 1.673; monoclinic; cleavage (110); twinned (100); Z = b; X near c; no crystals for study.

Souzalite is a fibrous, green hydrous iron magnesium aluminum phosphate with the formula $2R_2O_3$:3RO:$2P_2O_5$:$5H_2O$. The mineral is a hydrothermal alteration product of, and more abundant than, scorzalite in the pegmatite. Chemical analysis: Al_2O_3 = 26.07; Fe_2O_3 = 2.65; TiO_2 = 0.07; FeO = 11.49; MgO = 9.62; MnO = 0.31; P_2O_5 = 37.70; H_2O^+ = 12.04. The x-ray powder pattern is unlike any known phosphate. Specific gravity is 3.087; biaxial (−); 2V medium; dispersion, extreme; X near 1.623; Y (blue) near 1.640; Z near 1.652; monoclinic (?); cleavage (010); twinned (100); X = b and Z near c. No crystals available for study.

The mineral assemblage includes albite, muscovite, quartz, apatite, zircon, and tapiolite, and the pegmatite can be subdivided into a central and border zone, each displaying characteristic texture, structure and mineralogy.

CONTAMINATION OF GROUND WATER FROM A PROPOSED SHIP CANAL, LOS ANGELES HARBOR, CALIFORNIA

VLADIMIR P. PENTEGOFF

The economic feasibility of constructing an unlined sea water-ship canal to extend 5 miles inland from Los Angeles Harbor has been studied recently by the Corps of Engineers, Los Angeles District. The present paper is a modification of the geological report appended to this study. The area in which the canal would be located is dependent for its fresh-water supply on ground water pumped from wells in that vicinity. The danger of contaminating this water by salt water from the canal was recognized.

The United States Geological Survey, in a recent study, has identified the local aquifers as members of Recent, Pleistocene, and Pliocene or older sediments. Hydrologically these aquifers constitute a semi-parched water zone, several main fresh-water zones, and a deep salt-water zone. Hydraulic continuity between the sediments that would be exposed in the ship canal and the underlying aquifers is believed to exist. Sea water is already encroaching on the fresh-water zones as a result of excessive pumping, and continued unabated withdrawal ultimately will cause total contamination. Excavation of the proposed canal, if done in the near future, would materially accelerate this contamination and would contribute considerably to great economic loss that would result from such contamination. The contamination from the canal would not occur if the water table were raised above sea level, or if sewer water (treated), which at present is wasted into the ocean, were used in operating the canal. Plates accompanying this paper illustrate all pertinent data.

RELATIONSHIP OF CYCLOTHEMS TO DAM DESIGN

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The key to the understanding of the general case in engineering geology of the Pennsylvanian rocks of the western Appalachians, particularly in the Ohio Valley upstream from Huntington, W. Va., is provided by the concept that those rocks are a succession of cyclothems. In this area a cyclothem presents an expression of the general shale and sandstone foundation case complicated by the interbedded addition of weak clays of all types, brittle limestones in which solution is commonly a minor factor, and coals in which mining may be a major and controlling factor. Although few cyclothems are complete with all members represented, all cyclothems are composed of rocks of nonmarine and marine origin and of widely differing physical and chemical characteristics which are reflected in their differing resistance to erosion and differing behavior under stress and relief from stress. This heterogeneity of rock types in cyclothems affects the selection of site, choice of type of dam, foundation design and treatment, design of temporary and permanent rock slopes, the protection of spillway and stilling basin floors, and the design of tunnel timbering.

For example, if the usually excellent basal sandstone occurs unweathered immediately under the alluvium the dam site may be considered suitable for a masonry dam, although the abutments would encounter the poor underclay, coal, and some of the weaker marine shales before being founded on the basal sandstone of the next higher cyclothem. However, if the valley bottom were located on one of the weaker members higher in the cyclothem, the dam would have to be designed for lighter foundation loading, or deeper excavation would be required to reach the basal sandstone with consequent increased cost, or an alternate site would be selected, if available.

Examples of the relationship of cyclothems to the design of Conemaugh, Crooked Creek, Loyalhanna, Tygart, and Youghiogheny Dams of the Corps of Engineers are presented.

METHODS OF STUDY OF RECENT FORAMINIFERA

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There is need for more accurate work on the ecology of Recent Foraminifera, to be used as a key in interpreting the environment of deposition of fossil assemblages. Sampling techniques and laboratory analysis need revision.

A new type of bottom sampler obtains an undisturbed sample of the surface of the bottom, and living benthonic Foraminifera are preserved in formaldehyde. Quantitative plankton tows have been made in all depths of water for living planktonic forms. Frequent bathythermograph observations should accompany collection of samples of Foraminifera.

In laboratory analysis the benthonic and planktonic fractions are treated quantitatively and separately. Several techniques are used to determine which specimens were living at the time of collection. These are the following chemical color tests for protein: ninhydrin reagent, biuret test, and Millon's reagent. These tests have been applied successfully to several hundred samples.

RELATIONSHIP OF CAMBRO-ORDOVICIAN DOLOMITES TO FACIES BARRIERS IN TENNESSEE AND VIRGINIA

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The effectiveness of barrier control on the distribution of clastic sediments has long been recognized in the Valley and Ridge area of Tennessee and Virginia. Field investigations likewise indicate probable barrier influence on primary carbonate distribution.

The Copper Ridge dolomite (upper Cambrian), occurring along the northwest belts in Tennessee and Virginia, grades southeastward into the Conococheague limestone. The gradation isolith closely coincides with Clinch Mountain and the Saltville thrust. This line marks the approximate position of a later structural barrier of great effectiveness in facies control during the middle Ordovician, separating sections of the Allegheny Synclinorium to the northwest from the thicker, more clastic geosynclinal sediments to the southeast. Beekmantown rocks grade from predominantly dolomite northwest of this line to predominantly limestone to the southeast, indicating partial effectiveness during the lower Ordovician.

The sharp coincidence of the gradational isoliths of the dolomite and limestone facies with this structure strongly suggests some relationship to the distribution and origin of the dolomites. It is suggested that the barrier at times caused sufficient shallowing to prevent free flow of refreshing currents to the Synclinorium, allowing higher concentration of salts in that area. The resulting dolomite is considered primary in the sense that dolomitization took place penecontemporaneously with the deposition of, and prior to the consolidation of, the calcium carbonate.

Preliminary investigations along the probable northeastward extension (Adirondack Arch) of the above barrier in northern Virginia and southern Pennsylvania suggest similar dolomitization in the partially isolated Allegheny Synclinorium.

UNIT CELL OF MALACHITE

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The unit cell data for malachite given in the literature are those of Brasseur (1932) and were obtained from rotation photographs. Weissenberg photographs confirm his cell dimensions but indicate a considerable difference in the value of the angle β. Brasseur used the crystallographic value of 91°03′ (Goldschmidt setting) and apparently indexed his films on this basis.

Measurements on Weissenberg photographs, with rotation both about the c and b axes, give a value for β of 98°45′. Because of the large value of d_{100} and the small value of c_0, this is nearly the maximum angle possible. An angle of about 100° would be equivalent to a B-centered orthorhombic cell, with a doubled value for d_{100}.

The cell dimensions as found are:

$$a_0 = 9.42 \text{ Å} \qquad b_0 = 11.87 \qquad c_0 = 3.21 \qquad \beta = 98°45'$$

EARLY MIDDLE CAMBRIAN STRATIGRAPHY OF THE CANADIAN ROCKY MOUNTAINS

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Provisional results of new field work in the Cambrian of the southern Canadian Rocky Mountains are the following. The Mt. Whyte formation includes a thin basal layer with Olenellidae, whereas the main portion of the formation yields faunas (some of which are new and excellently preserved) indicating deposition much later. Assignment of this portion to the Middle Cambrian, as suggested by Burling, seems indicated. The overlying Cathedral dolomite is represented at certain localities by almost pure calcareous beds; the "Ptarmigan" limestone is only the lower, undolomitized portion of the Cathedral and must be suppressed as a formation. New faunas were discovered in the undolomitized Cathedral. Revision of the classic section on Mt. Stephen shows the inaccuracy of Walcott's work. The character of the sediments undergoes a deep change within the mountain; the entire Cathedral formation grades laterally from dolomite at the northeast to shale and thin-bedded limestone at the southwest. Walcott's composite section does not represent actual conditions at any one locality. The problem of the stratigraphic position of the *Ogygopsis* and Burgess shales will be discussed.

NEW MIDDLE CAMBRIAN FAUNAS FROM MT. STEPHEN, BRITISH COLUMBIA

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Mt. Stephen and Mt. Field near Field, British Columbia, occupy a peculiar position in the stratigraphy of the southern Canadian Rocky Mountains. The Cambrian section changes character within a short distance, from the limestones and dolomites at the east (Walcott's "Bow trough") to the shaly sediments at the west (Walcott's "Goodsir trough"). In a portion of the Middle Cambrian, this change in lithology can be observed within the above-mentioned mountains. At the same time, faunas are present that are not known elsewhere in the region: the *Ogygopsis* fauna on Mt. Stephen, and the Burgess shale fauna on Mt. Field.

The writer discovered in 1947 a new early Middle Cambrian fauna on Mt. Stephen, in a shale that does not seem to have been described before. This shale probably represents a deposit of limited lateral extent, like the other above-mentioned shales. It occurs stratigraphically about 350 feet above the top of the St. Piran sandstone and is probably younger than most or all of the Mt. Whyte formation. Another fauna, hitherto unknown in the area, occurs 150 feet higher in the section.

The fauna in shale includes many trilobites, represented by great numbers of splendidly preserved individuals. The most common and characteristic trilobite belongs to an undescribed genus somewhat intermediate between *Albertella* and *Zacanthoides*.

A new, rich fauna, somewhat older than the preceding, was discovered in a limestone at the base of Mt. Field. A few species from both localities will be illustrated by lantern slides.

IRON ORE DEPOSITS OF CENTRAL LABADOR AND NEW QUEBEC

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Since 1936, the senior author has directed geological mapping and prospecting in this region. The results of the work are reviewed briefly.

The rocks are of pre-Cambrian age. They consist of a series of ancient gneisses of Grenville type, overlain unconformably by a series of sediments and volcanics. The latter have been thrust-faulted and closely folded in a northwest-southeast direction, with the stresses coming from the northeast. This younger series bears a strong lithological resemblance to the iron-bearing rocks of Huronian age of the Lake Superior District.

The belt of younger rocks has a maximum width of 40 miles and a length of at least 350 miles and is commonly referred to as the "Labrador Trough". Iron-ore deposits have been found intermittently along the "trough" for a length of 90 miles. They occur as concentrations in iron formation along or close to faults, in synclines, and in drag folds.

To the east of the iron-bearing series is a belt of predominantly volcanic rocks some 25 miles wide, the age of which is unknown. They resemble rocks of Keewatin age but they might conceivably be of Keweenawan age. One deposit of base metals has been found within them.

Drilling of the iron-ore deposits is now in progress. Preliminary railroad and harbor surveys are being made. A landing strip has been constructed in the area. Ample water power for mining purposes is available. If drilling indicates a sufficiently large tonnage potential, Central Labrador and New Quebec may become a new, important source of iron ore on the North American Continent.

CONCRETE POP-OUTS DUE TO REACTIVE AGGREGATES

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The problem of reactive aggregates in concrete has been of serious concern to concrete engineers for the past several years. In 1940, T. E. Stanton (Materials and Research Engineer, California Division of Highways, Sacramento) discovered that certain unsound conditions in concrete were due to a chemical reaction between amorphous chert (opaline silica) and the sodium and potassium contained in normal Portland cement. Since Mr. Stanton's discovery the list of minerals and rocks known to be reactive has increased, and it now is the geologist's problem to determine whether or not a given rock, gravel, or sand contains one or more of these reactive constituents.

A predominant indication of a deleterious reaction in a concrete is the development of pop-outs and/or an intricate pattern of fine cracks on the surface of the concrete structure. Since these manifestations may occur also from other causes, one must make complete petrographic examinations of the aggregates and of the unsound concrete to be sure the deterioration is due to aggregate reactivity.

Pop-outs accompanied by some pattern cracks have been observed in the concrete of two dams and the concrete lining of a river channel built a few years ago by the Corps of Engineers, Department of the Army, in the vicinity of Los Angeles, California. This paper is concerned with the cause of these pop-outs. The pop-outs are described and illustrated. Petrographic analyses of the gravels and sands used in the concretes are reported, and it is shown that a small percentage of amorphous chert contained in a soft shale constituent of the gravels and sands was the cause of the pop-outs. Petrographic evidence of chemical reaction between this constituent and components of the cement are described and illustrated with photomicrographs, and the probable mechanics of the reaction which causes the pop-outs are briefly discussed.

SOME FIELDS OF IGNORANCE IN ENGINEERING GEOLOGY

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Increasingly large and complex engineering structures are being built on foundations and with materials which formerly were unacceptable. More precise engineering design is required but is possible only if the natural conditions—the geology—to which the structure is to be adapted are thoroughly understood. The geologist is challenged to interpret these conditions, precisely and quantitatively, in terms of their engineering significance.

Recent Reclamation problems emphasize some "fields of ignorance" which must be dissipated through research.

Stress and Strength Characteristics of Bulk Rock Masses. The physical characteristics of small specimens bear little relation to those of whole foundations which always possess inhomogeneities. Determinations of residual stress in Prospect Mountain Tunnel, of "elastic modulus" of Davis Dam power-house foundation, and the general reaction to stress in rock masses are discussed.

Landslides. Neither theory nor observational data permit confident prediction of potential slides. Grand Coulee reservoir slides, slope analysis for deep excavation at Tracy Pumping Plant, and certain factors which presently defy analysis are discussed.

Swelling Clays. Swelling clays which may lift and deform structures are discussed with special reference to Delta-Mendota and Friant-Kern canals, and current research is described.

Concrete Materials. Usual tests disclose whether a concrete aggregate is "good" or "bad" rock but ignore its "compatibility" with cement. A new approach toward determination of "concrete-making" properties of potential aggregates is suggested.

These random examples illustrate the need for wide field and laboratory research in which the geologist must enlist the technical resources of all related sciences.

PRESERVATION OF FOSSIL JELLYFISH

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Fossil jellyfish are only rarely found in geological formations. This is not surprising considering the delicacy of their structure and the fact that they are more than 90 per cent water. Recent observations on jellyfish stranded on the beach of the Gulf of Mexico at Biloxi, Mississippi, and the Gulf of California at El Golfo, Sonora, give some clues to the possible method of preservations of such fossils.

SPECIES PROBLEMS IN SOME FAMILIES OF OSTRACODERMS

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A survey of recent literature concerning the Osteostraci gives some basis for agreement on species criteria in this order. An attempt is made to correlate these criteria with those used in classification of some recent vertebrates, and on this basis to scrutinize the species of some of the fossil groups.

SYNTHESIS OF LEAD SULPHANTIMONIDES

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Lead sulphantimonides were synthesized by dry fusion in vacuum and from various aqueous solutions in a closed system at temperatures up to 425°C and at pressures up to 2000 bars, and the products were correlated with natural minerals by x-ray powder and Weissenberg photographs. Only two lead sulphantimonides were synthesized by dry fusion in vacuum: boulangerite and mineral "X", a new mineral from the Red Bird mine, Nevada, which has not as yet been named. From aqueous solutions artificial equivalents of fuloppite, plagionite, semseyite, zinkenite, and mineral "X" were synthesized, together with two other lead sulphantimonides for which natural counterparts are unknown. Products of hydrosynthesis were sealed in vacuum and subjected to temperatures below their melting points (about 380°C) for 2 weeks. Outward crystal forms of these products remained unchanged, but in every case partial to complete alteration to boulangerite, mineral "X" or galena, with deposition of a brown sublimate of stibnite, had occurred.

The minerals reproduced by hydrosynthesis are typical of the epithermal environment; minerals of mesothermal association were not obtained in this way. Sulpho-salts form most readily from alkaline and variably sulphurous solutions; acid solutions result in deposition of lead and antimony sulphides with, rarely, traces of lead sulphantimonides. Neutral chloride salts facilitate formation of these sulpho-salts; carbonates and bicarbonates repress such formation.

GARNET-IDOCRASE ROCK, A PSEUDO JADE FROM PLACER COUNTY, CALIFORNIA

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A massive rock occurring in connection with serpentine proves on optical examination to be an intimate mixture of grossularite and idocrase. The idocrase occurs in minute porphyroblasts disseminated through the granoblastic garnet and is apparently a product of retrogressive metamorphism.

The rock varies from white and gray to greenish gray and has interesting brownish-red mottlings. It is an attractive ornamental stone especially in thin slabs by transmitted light.

It is essentially different from californite although the latter term might be expanded to include it.

Attention is called to the variability of idocrase in various occurrences.

MINERALOGY OF THE BALLAST SANDS OF JAPANESE BALLOONS

CLARENCE S. ROSS

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The beach sands of the Japanese balloons dispatched to this country in great numbers were submitted to the Section of Military Geology of the U. S. Geological Survey. Detailed studies indicated that these showed such an unusual suite of minerals that it would be possible to indicate their probable source on the coast of Japan. The minerals of these sands and their characteristics will be described in detail.

EASTERN FRONT OF THE BITTERROOT RANGE NEAR HAMILTON, MONTANA*

CLYDE P. ROSS

U. S. Geological Survey, Washington, D. C.

The correct interpretation of the origin of the steep and relatively straight portion of the front of the Bitterroot Range that forms the western border of the long valley in which Hamilton, Montana,

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is the principal settlement, has been of interest to geologists since Lindgren's reconnaissance in 1899, on the basis of which he interpreted the gneissic rocks forming the range front as a result of crushing along a fault. Broadly similar interpretations have been accepted by other geologists. Field studies in 1946 and 1947, made in connection with the compilation of a proposed new geologic map of Montana, led to the view that the gneissic material results from injection and replacement of sedimentary rocks by igneous juices related to the Idaho batholith. According to this interpretation, the range front is a dip slope in metamorphosed strata belonging to the Belt series (pre-Cambrian) rather than a fault or fault-line scarp. Throughout much of its extent the Idaho batholith is bordered by highly metamorphosed rocks which, in many places, are intricately intermingled with igneous material. Many of the igneous rocks in the border zone are gneissic, and some are clearly the result of injection into bedded rocks. The more complexly gneissic parts of the border zone were thought by Lindgren and others to be of pre-Cambrian age but they have since been shown, in several localities, to be genetically related to the Idaho batholith which is not older than late Mesozoic. The injected material in these complex portions of the border zone differs from that in the Bitterroot front west of Hamilton principally in the fact that the thick and competent rocks in the latter locality have not been contorted. On the contrary, they constitute a portion of the rocks bordering the batholith that was tilted eastward at angles of 15° to 25°, but not otherwise deformed during the doming that accompanied intrusion. Probably both thrust and normal faulting have occurred in the general vicinity of Hamilton, but the resemblance of the front of the Bitterroot Range in that area to a fault scarp is believed to be purely coincidental.

LATE CRETACEOUS AND EARLY TERTIARY CORRELATION IN ALBERTA AND SASKATCHEWAN

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The author's previous conclusions on the Cretaceous-Tertiary problems of the Canadian Plains region are reviewed in the light of recent studies by various workers. The progressive withdrawal of the Bearpaw sea is now fully established. Youngest marine deposits occur in southwestern Saskatchewan and are correlated with the Lower Fox Hills (Eastend formation). The Fox Hills stage is also represented by most of the Edmonton and St. Mary River formations of Alberta, and by the Whitemud and Battle formations of Saskatchewan. The Lance stage is now known to be represented by the uppermost Edmonton (and probably St. Mary River) and by the Frenchman formation (formerly called Lower Ravenscrag) of Saskatchewan. Contrary to the view of some, the Frenchman is not represented in southeastern Alberta. The earliest dated Tertiary of the region occurs in the central Alberta foothills, where plant and mammalian fossils indicate at least Middle Paleocene. The Paskapoo formation of the plains is not older than Upper Paleocene, the earlier stages being represented by the Edmonton-Paskapoo unconformity. The Willow Creek formation of southwestern Alberta has been referred to the Cretaceous, but fossil evidence still favors a Paleocene age. The Ravenscrag of Saskatchewan is still regarded as Paleocene. Intense erosion of the plains in Eocene time, suggested by the occurrence of Late Eocene sediments at low elevations, is confirmed by structural studies in the Cypress Hills area.

POST-GLACIAL MASTODON REMAINS FROM SOUTHWESTERN ONTARIO

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Mastodon bones, teeth, and tusks have been obtained from a swamp deposit near Rodney, Ontario. The lower tusks give some indication of the manner of feeding. The remains occur in a black vegetable muck, 2 to 3 feet in thickness, resting unconformably on sand and gravel. The contact follows the present land surface. The swamp deposit is local, but the underlying gravel has been traced into a Lake Wittlesey beach deposit. Geological evidence thus indicates a post-Whittlesey age for the bones. Topographical features suggest an even more recent dating—*i.e.*, post-Nipissing.

GROUND-WATER INVESTIGATIONS IN THE UNITED STATES

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In 1945 it was estimated that an average of about 20 billion gallons of ground water was used for municipal, industrial, irrigation, and domestic uses in the United States each day. This represents an increase of nearly 100 per cent since 1935 and has resulted in an increasing demand for information on the ground-water resources. Most of the basic ground-water investigations in the United States are carried on by the U. S. Geological Survey in co-operation with State, county, and municipal agencies in 42 States and in all of the major ground-water provinces in the United States, in Alaska, Puerto Rico, and the Hawaiian Islands. A large part of this work is in co-operation with the State Geological Surveys. These investigations are being made to determine the occurrence, quantity, and quality of ground waters that are perennially available. Studies are also being made to determine the nature of movement of ground water through the soil, the use of ground-water level fluctuations in forecasting low stage flow of streams, and a score of other problems.

The earliest ground-water investigations in the United States were necessarily chiefly reconnaissance over large undeveloped regions with the purpose of locating usable aquifers. Gradually the reconnaissance surveys are being succeeded by more thorough and systematic surveys. Now most ground-water investigations by the U. S. Geological Survey are either systematic areal surveys, or special investigations. The special investigations generally involve intensive geologic studies together with detailed quantitative determinations of coefficients of transmissibility and storage to obtain knowledge of the perennial yield and optimum distribution of wells and rates of withdrawal.

PRESENT STATUS OF LABORATORY STUDIES OF DRY SILICATE SYSTEMS

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Phase-equilibrium studies of dry silicate systems, which are now in progress or have just been completed at Geophysical Laboratory, yield much information on the ranges in chemical composition and on the mutual stability relations at elevated temperatures of several groups of important rock-forming minerals—particularly the olivines, pyroxenes, pyroxenoids, melilites, feldspars, and feldspathoids. Progress on the following systems is reported: Na_2O-Al_2O_3-SiO_2, K_2O-Al_2O_3-SiO_2, nepheline-potash nepheline-silica, leucite-anorthite-silica, leucite-forsterite-silica, nepheline-diopside-silica, nepheline-anorthite-silica, CaO-MgO-Al_2O_3-SiO_2, CaO-MgO-FeO-SiO_2, K_2O-MgO-SiO_2, and K_2O-MgO-Al_2O_3-SiO_2.

EXCELSIOR SURFACE—AN INTRA-COLUMBIA RIVER BASALT WEATHERING SURFACE*

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The existing concept of the Columbia River basalt is that of a series of essentially horizontal lavas formed during one protracted period of extrusion. During some of the numerous short breaks in the extrusive activity, a few feet of residual clay was produced from basalt, or rapidly accumulating beds of clastic materials were deposited, but such interflow activities do not greatly alter the existing concept. However, basalt-derived residual clays up to 124 feet thick were hand-drilled during wartime investigations of clay deposits of eastern Washington and northern Idaho. Residual clay of such thickness indicates a long period of weathering and a cessation of eruptive activity. This period of weathering produced a mature surface with integrated drainage. This surface extended at least throughout eastern Washington and adjacent parts of northeastern Oregon and northern Idaho. The zone of deep weathering locally crossed the contact of the basalt and the older crystalline

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rocks that border and underlie the basalt field. The deposits of basalt-derived and granite-derived residual clays and the thick weathering profiles throughout this area are considered to have a common history.

The writer first studied this erosion surface at the basalt-derived residual clay deposit near Excelsior, Washington, 11 miles southeast of Spokane. The Excelsior surface may have extended to the Pacific Ocean, and possibly the ferruginous bauxite deposits of the Portland region were developed on it. The weathering period of the Excelsior surface may have extended from early Miocene, or even Eocene, to late Pliocene. The Excelsior surface was partially flooded by later flows of the Columbia River basalt. The writer uses the terms, lower basalt flows and upper basalt flows, respectively, for those flows extruded before and after the formation of the Excelsior surface. Further investigation may indicate that these two groups of flows differ sufficiently in petrologic characteristics and in age to be considered products of two distinct periods of eruptive activity and to warrant separate stratigraphic names.

CLAYS OF THE MONTMORILLONITE-NONTRONITE GROUP IN BASALTIC ROCKS NEAR GOLDEN, COLORADO

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Recent examination of basaltic rocks from a quarry at South Table Mountain, near Golden, Colorado, to determine their suitability as concrete aggregate has revealed the presence of small amounts of the iron-bearing member of the montmorillonite group, nontronite. The basaltic rock contains microphenocrysts of labradorite, olivine, and augite in a microcrystalline groundmass of automorphic labradorite and xenomorphic orthoclase with small amounts of biotite, magnetite, and bluish apatite. Not described previously, the nontronite occurs in altered facies as aggregations of yellowish- and browish-green flakelike crystals partially or completely replacing olivine, augite, and labradorite.

Following this study, the Ralston dike, 4 miles northwest of the quarry and composed of similar rock, was re-examined. Here too, clay minerals of the montmorillonite group occur, especially in hydrothermally altered zones composed of nodules of hard, altered basaltic rock in a matrix of soft, decomposed material. The clay minerals are present in both the nodules and matrix. As indicated by optical properties and X-ray diffraction data, the clay minerals represent a series ranging from near montmorillonite to nontronite. The largest interplanar spacing, which also corresponds to the strongest, powder-method diffraction line, is 14.8 Å. The montmorillonite group minerals occur as partial or complete replacements of olivine, biotite, augite, and labradorite, and as rims on magnetite; peripheral zones about olivine typically grade outwardly from a montmorillonitelike mineral to nontronite.

Examination of samples from many parts of western United States indicates that altered basalts almost invariably contain nontronite, commonly in association with other members of the montmorillonite group.

VARIABLE COALIFICATION—THE PROCESSES INVOLVED IN COAL FORMATION*

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Coalification involves the genetic and metamorphic history of coal beds. The plant materials that form coal may be, in part, simply incorporated, or they may be present in vitrinized or fusinized form. Materials contributing to coal differ in their response to diagenetic and metamorphic agencies, and the three essential processes of coalification are called incorporation, vitrinization, and fusinization. The processes are defined on the basis of petrographic characteristics. A diagram illustrates the extent of change in the plant material, in comparison with diagenetic and metamorphic intensity.

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Since coal beds generally include various proportions of the diverse materials resulting from the three processes, practical classification of coal is intimately related to the part each process has played.

TEMPERATURE OF FORMATION FROM FLUID INCLUSIONS

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In collaboration with Dr. F. G. Smith a simple technique has been developed whereby primary liquid and gas inclusions in a mineral may be utilized to determine its approximate temperature of formation. The mineral is prepared by crushing and screening and is placed in an electric furnace whose temperature is steadily increased. The temperature at which the expanding liquid just fills the cavity is accepted as the temperature of formation and is usually determined visually with the microscope; in the present procedure, the frequency and volume of exploding inclusions is recorded, providing data from which the temperature is interpreted. By this means the temperature of formation of quartz in the Ivigtut (Greenland) cryolite deposit was determined as at least 320°C. The inversion temperatures of several minerals studied, including quartz and cryolite, have a marked influence on the audible effect, and inversion points may in some cases at least be predicted from this effect alone.

LARGE-SCALE SHEARING WITHIN AN ALPINE GLACIER IN THE SOUTHERNMOST ANDES*

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Large-scale internal shearing was observed in an alpine glacier in the southernmost Andes. The glacier lies in the northwestern part of the Cordillera Darwin in western Tierra del Fuego, immediately south of the Strait of Magellan. The Cordillera, in the early stage of mature alpine glaciation, is a largely unexplored range of metamorphic and igneous rocks that supports several ice fields and numerous alpine glaciers.

One of the most interesting glaciers, unnamed and previously undescribed, flows westward from a large ice field and is situated approximately at Longitude 70° 15′ W., Latitude 54° 35′ S. Observations and photographs made from low-flying aircraft indicate that the glacier is 5 miles long and approximately $1\frac{1}{4}$ miles wide. At a point about a mile from its end, the relatively clean, light ice in the upper portion of the glacier appears to have been thrust forward over the under part along two subparallel shear planes. Ground moraine, carried to the surface by the shearing, is visible along the traces of the shear planes. The traces of these planes are arcuate lines, subnormal to the long axis of the glacier, and are convex toward its foot. The shears are also exposed in cross section on the northern side of the glacier. The overriding ice may represent an advance which covered a stagnant or almost stagnant remnant of the glacier. Recurring climatic fluctuations may account for such advances.

PARAGENESIS OF THE GARNET AND ASSOCIATED MINERALS OF THE BARTON MINE NEAR NORTH CREEK, N. Y.

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During the spring and late summer of 1947, the writer collected from the Barton Garnet Mine on Gore Mtn. near North Creek, N. Y., a number of specimens of the garnet and associated minerals for a paragenetic study which was suggested by the occurrence of hypersthene crystals up to 4 inches in length extending from their attachment in the hornblende rims into the garnet masses. These vary in size up to a foot in cross section. Other hypersthene crystals up to $1\frac{1}{2}$ inches long were inclosed within the garnet.

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In addition to the usual rather thick envelope of hornblende surrounding the garnet, commonly a thin envelope of plagioclase feldspar appears between the hornblende and garnet. The feldspar sometimes produces envelopes or irregular masses up to an inch thick. Euhedral crystals of hypersthene and terminated crystals of hornblende are associated with the larger masses of feldspar. A number of other minerals occur at the contacts and/or wholly within the plagioclase or garnet.

The textural and structural relationships suggest that the direction and order of crystallization was centripetally from the surrounding mass of the inclosing gabbroic rock to the garnet which, except for the acid plagioclase, was the last mineral to crystallize.

DIVING OPERATIONS IN CALIFORNIA SUBMARINE CANYONS

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A diver has been employed to observe conditions on the bottom of submarine canyons off La Jolla, California. Photography was intended to form a large part of the program, but to date it has been rare that the water was sufficiently clear to allow good photographs, particularly along the canyon axes. The murk has been due in part to plankton and in part to fine sediment which is carried into the canyons by rip currents and settles very slowly. The mud stirred up by the diver also interferes with visibility particularly because the currents are generally too weak to carry away the mud cloud in a short period. The walls of Scripps Canyon are rocky, but coated to a considerable extent with marine growths. Cliffs and even overhanging slopes are found in many places. The canyon walls are cut by tributaries, and some of these tributaries enter the main valley as hanging valleys. Scripps Canyon is closely similar to land canyons which are directly adjacent to it. The canyon bottoms are narrow and largely choked with kelp and muddy sediments, although rock outcrops are found sparingly. The decomposition of the kelp may assist the development of the mud flows which are thought to keep the canyons from being filled.

La Jolla Canyon has much less rock exposed at its head than Scripps Canyon. The steep muddy slopes at the head of this canyon are interrupted in places by vertical cliffs of alluvium which include layers of cobbles.

HAWAIIAN SUBMARINE CANYONS

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Little has been known of the submarine topography off oceanic islands because of the inadequacy of surveys. During the past spring, operations of the U. S. Navy involved surveys off Hilo, Hawaii, and Kaneohe Bay, Oahu. At the writer's request lines of soundings were also run off the precipitous north coast of Molokai. These soundings have definitely established the existence of submarine canyons comparable to those found off continental coasts. The canyons were discovered off the deeply eroded windward coasts of East Molokai and northeast Oahu. Some of them appear to be definitely related to land canyons. The canyons have been traced to depths of at least 500 fathoms.

Sounding lines off the recent lava flows of Mauna Loa and the relatively recent flows of Mauna Kea do not show canyons. Scattered soundings from other parts of the Hawaiian Island suggest that other canyons exist off old deeply eroded volcanic masses and are missing off other areas of more recent vulcanism.

FOSSILS IN LATERITE AND BAUXITE

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Under certain conditions of chemical weathering mantles of laterite and bauxite are developed on favorable source rocks. Such conditions are most common in tropical regions, though not limited to them. Certain plant structures and animal hard parts may be incorporated in the residual soils and ultimately preserved. In this fashion a fossiliferous soil could be formed and the fossils used to determine the approximate age of the deposit and of the degradational surface or unconformity on which it rests. A case in point is illustrated by present conditions in Jamaica. There a discontinuous mantle of ferro-aluminous soil lies on a karstland deeply etched into the massive White limestone of Tertiary age. Small cavities, crevices, and other depressions in the limestone are filled with a mixture of red soil and well-preserved snail shells cemented with calcium carbonate. Some accumulations are little cemented and disintegrate readily; others are so firmly and completely cemented as to form true rock. Were the latter to be buried at some later date by incoming sediments, they would constitute masses of fossiliferous bauxite. The included shells, which could be used to date the soil, are similar to those of snails now living on the karst surface. An ancient deposit of essentially the same nature has been reported from Bermuda.

LOIPONIC DEPOSITS

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Intense and prolonged chemical weathering of rocks produces a surficial layer of material composed largely of certain original constituents of the source rock. It is proposed that this residual layer be named the ***loipon*** (from λοιπόν, Greek, meaning residue; pronounced as though spelled loy'-pon) and that accumulations of this kind be designated *loiponic* deposits. Typical examples are the gossans over many ore bodies, the well-known lateritic iron ores of Cuba, Puerto Rico, and the Philippine Islands (Mindanao), the limonitic iron ore and ferruginous bauxite of northwestern Oregon, the several ferro-aluminous deposits in Jamaica, Haiti, and the Dominican Republic, the bauxite deposits of Arkansas, Hungary, and elsewhere in many parts of the world, and the terra rossa deposits of Europe. The foregoing include examples of unusually large metalliferous bodies. Another kind of loiponic deposit is the laterites of India, the red clays in mid-latitude and tropical regions, the duricrust of Australia, and crusts of different kinds which accumulate at and near the surface in arid regions.

Loiponic deposits have economic importance when they can be used as a source of metal, as ceramic material, or for construction. They yield iron, aluminum, copper, nickel, chromium, and manganese in commercial amounts, and some contain appreciable quantities of several strategic metals not usually detected or sought in routine assays. Future prospecting should consider the possibility of commercial concentrations of rare metals in recent and ancient loiponic deposits, especially in the tropics.

The loipon develops as a residual deposit on degradational surfaces, hence ancient loiponic accumulations lie upon preserved portions of such surfaces, either as presently exposed mantles or as buried formations along unconformities. Few ancient loipons have thus far been reported. Some have been inferred from stratigraphic relations. For example, the Clinton iron ores of New York and Wisconsin indicate land conditions which favored release of iron from weathering of near-by pre-Cambrian rocks, and the limonite ores of Oregon indicate loipon formation between Miocene lava flows. Some ancient loiponic deposits may have been metamorphosed so intensely that their true nature has been overlooked.

Loiponic deposits should be interesting to geologists because of possible importance as a source of both common and rare metals, because they mark unconformities, and because they have been the parent of certain unusual metamorphic rock bodies.

PLEISTOCENE GEOLOGY OF THE YANKTON AREA, SOUTH DAKOTA AND NEBRASKA*

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Pre-Iowan, Iowan, and post-Iowan drift sheets are found in the Yankton area, South Dakota and Nebraska. The fluvial Grand Island formation (Kansan, and earlier?), the Pearlette ash of

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Condra (Yarmouth), the Loveland loess (Sangamon), and loesses of Iowan and post-Iowan age also occur.

Field identification of the respective tills is based primarily on stratigraphic relations, and on comparative lithologic characteristics. From the grayish till (pre-Iowan) through the olive-drab (Iowan) to the yellow-brown till (post-Iowan) there is progressively a sharp decrease in joint development and compactness, a sharp decrease in development of manganese and iron oxides as coatings on joint and pebble surfaces, a prominent increase in the number and size of boulders, and a recognizable increase in the sand-size fraction. Laboratory analyses yield supporting data.

Previous to this year Iowan ice was not known to have crossed the Missouri River into Nebraska, but Iowan till is now known to occur at least 23 miles south of Yankton. Evidence of the age of this till is indicated in exposures showing Iowan till overlying pre-Iowan till or the Pearlette ash, and overlain by eolian deposits of Iowan age.

The only drift border occurring within the area is of post-Iowan age, but no evidence has been found to indicate that post-Iowan ice crossed the Missouri trench. Generally the border of the post-Iowan drift lies 1–3 miles north of the river, reaching it only via tributary draws.

WIND EROSION IN SOFT ROCK

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At scattered localities in the Great Plains, modern sand blasting on chalk and semi-indurated sand duplicates certain of the erosional effects reported to occur on harder rock in true deserts, and contributes to the understanding of wind erosion in general. At one place, sand blown over a low bluff in Cretaceous chalk has, in about 30 years, produced numerous small ventifacts and has developed rounded and fluted rock surfaces. At several places, ancient deposits of semi-indurated dune sand have been eroded in distinctive fashion. Bedding has been etched in relief; fluted, pitted, and knobby surfaces have been produced; and miniature ridges of streamlined form have been carved out. Where buried soil zones form slightly more resistant layers, their eroded remnants stand out as low platforms or humps, with blunt, undercut sides to windward and tapering sides to leeward. Where erosion has been vigorous for some time, irregular troughs and shallow basins have been excavated. At one locality, where a marly caprock is present, the sides of the basin are locally abrupt, and miniature mesalike outliers stand isolated by erosion.

USE OF FELDSPAR IN THE PETROFABRIC ANALYSIS OF IGNEOUS ROCKS

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Microscopic statistical analysis has not kept pace with granite tectonics as a tool in the structural study of igneous rocks. The methods of petrofabrics are rarely applied to igneous problems and when used rely chiefly on studies of quartz and the micas.

The omnipresent feldspars are readily oriented with the five-axis universal stage and are more useful in studies of igneous rocks than the more restricted quartz and mica. Although the elements in the feldspars suitable for measurement are limited by the variable relations of the indicatrix to crystallographic directions and by twin relationships several elements give reliable data. Measurements of both lineation and foliation can be made on the same mineral.

Adaptations of the Fedorov plagioclase stereograms permit measurements to be made on an easily oriented crystallographic element while the plotting may be done for a more desirable element or section. Petrofabric data are more easily interpreted if included as a part of the structural map and sections.

Study of a granitic intrusive in north-central Wisconsin by both megascopic and microscopic methods indicates that the two methods complement each other and that microscopic data may be used where megascopic data are incomplete or lacking. Microscopic analysis frequently reveals several structural elements whereas only the dominant one may be visible in outcrop.

NEW DINOSAUR FROM SOUTHERN ALBERTA, REPRESENTING A NEW FAMILY OF THE CERATOPSIA

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Two skulls collected from Edmonton formation on Little Bow River represent a new family of the Ceratopsia. The skull is subrectangular, short, deep, and massive. There were no horns, but the top of the head is up to 12 inches broad and concave superiorly. The nasal and frontal bones are as much as 8 inches thick, and the lateral sides are strongly striated. Teeth short with great lingual-bucal width. Occipital condyle points strongly downward suggesting that the nose was depressed, and the broad, thick skull roof served as a battering ram. The crest was short and strongly arched.

GEOMORPHOLOGY AND STRUCTURE OF THE WEST KAIBAB FAULT ZONE AND KAIBAB PLATEAU, ARIZONA

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The western flank of the Kaibab Plateau contains three principal normal faults, all downthrown on the west, and locally including monoclinal flexures. About half the total displacement of 3000 feet between plateau summit and adjacent Kanab platform is accomplished by these faults and monoclines, the other half by strong westward and northwestward regional dips. Strata on downthrown sides of major fault lines show downbending toward fault planes and indicate sagging of the edge of the lowered plateau blocks during faulting. Numerous minor faults, grabens, and swells affect the plateau arch. All deformational structures of the Kaibab region, including the East Kaibab monocline, are regarded as Laramide in age, although positive stratigraphic evidence is lacking.

The plateau is dissected by numerous resequent and subsequent streams which follow the dip of the resistant, stripped Kaibab limestone or occupy fault lines. Resequent fault-line scarps have appeared following removal of weak Triassic shales.

No evidence was found of peneplanation in a former erosion cycle. Small pediment remnants near the lower flanks of the plateau arch are interpreted as local features not requiring regional base leveling.

The ancestral Colorado River in the Kaibab region is postulated to have developed along a belt of weak Triassic shales which formerly encircled the southern end of the plunging Kaibab arch. Later intrenchment into resistant Paleozoic strata and removal of Mesozoic beds from the area have made the river appear to cut discordantly across the Kaibab arch.

QUANTITATIVE GEOMORPHIC STUDIES IN THE VERDUGO AND SAN RAFAEL HILLS, CALIFORNIA

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Three small areas on the south side of the Verdugo and San Rafael Hills were selected for quantitative study of topographic forms and drainage systems developed in igneous and metamorphic rock masses maturely dissected under a Mediterranean-type climate.

As one phase of the investigation 500 slope angles, measured on lower walls of small ravines, were subjected to frequency-distribution analysis. Arithmetic means of 44.7° and 42.4° were obtained for two small areas underlain by San Gabriel metasediments and associated intrusives; 42.3° for a third area, underlain by Wilson diorite. This suggests that rock difference has been less important than other factors in determining steepness of slopes.

A high degree of homogeneity of slope angles is shown by standard deviations of 3.4°, 2.6°, and 3.8° in the three areas, and by a range of 18° or less within each group. Frequency distributions are symmetrical and fit closely the normal curve of error. Normal distribution and low dispersion suggest that slopes retreat at a constant angle so long as ravines are being actively deepened.

Slopes long protected from stream cutting, as evidenced by basal talus, were found to have mean of 38.2° as compared with 44.7° for slopes which are being refreshed at the base by stream corrasion. The difference is highly significant and indicates declining, rather than parallel retreat of protected slopes.

Slopes facing north have denser vegetation and thicker soil than south-facing slopes, but arithmetic means of slope angles of the two groups showed no significant difference.

SLOPE-PROFILE CHARACTERISTICS OF THE VERDUGO HILLS, CALIFORNIA

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In conjunction with studies of slope angles, drainage patterns and densities, relief, and other topographic elements of the maturely dissected Verdugo Hills 22 profiles were surveyed with steel tape, hand level, and Brunton compass in areas recently denuded by brush fires. Each profile extends from divide to adjacent ravine bottom, following the line of steepest slope.

Most striking characteristic of the profiles is a straightness of line from base to a point near the top, where divide curvature sets in. The straight portion constitutes from 60 to 85 per cent of the whole profile and usually varies less than 1° from a true straight line. With increased over-all relief the straight profile segments are longer, accentuating the effect of slope straightness in higher, more rugged parts of the mountain mass.

Slopes of the straight profile segments range from 28° to 43° from one locality to another. Where less than 38°, there is present at the lower end of the profile a steeper straight segment, or facet, ranging from 41° to 47°. The composite profile is interpreted as a product of rejuvenation of the drainage system. Rapidly retreating steep slopes are replacing old slopes which had declined in a former period of limited stream activity.

Divides are smoothly rounded and have a thin but fairly uniform soil cover. No correlation was found between sharpness of divide curvature and steepness or length of tangent straight slopes. Sharpness of curvature varies considerably without regard to position in the drainage system.

GOLD CRYSTALS FROM THE SOUTHERN APPALACHIANS

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Gold in well-formed rhombic dodecahedra is reported for the first time from the Southern Appalachians. The crystals were obtained from placer deposits in Greenville County, South Carolina. Poorly developed octahedra, dendritic forms, and wire gold have been reported from Georgia. Euhedral gold crystals are extremely rare compared with the amount of the metal produced, and very few have been preserved.

Euhedral crystals and filiform gold develop in open spaces, for gold is too soft and malleable to displace most other minerals. Also because of these properties crystalline structure is readily destroyed by impact or even by polishing, but the high mobility of the atoms makes recrystallization easy. Euhedral crystals are deposited from solutions occupying the cavities. Wirelike forms of the native metals result when the material for growth is available in only one direction, the wires being pushed into the cavities by the addition of atoms at their base from solutions occupying small pore spaces in the walls.

LATE QUATERNARY SEQUENCE AND EARLY MAN IN THE VALLEY OF MEXICO

HELMUT DE TERRA

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The Upper Pleistocene and Recent are recorded by a glacial sequence on the high volcanos and by alluvial and lake deposits in the lake basin. Three glacial substages are represented by moraines and outwash deposits reaching some 1600 m below the present ice limit. They are held to represent the three Wisconsin glaciations. A post-Pleistocene ice advance formed a prominent terminal moraine. Between it and the present ice border lie two sets of recessional moraines. The correlative divisions of this glacial sequence were found in the valley basin where three alluvial formations could be distinguished in addition to three terraces of Recent age. The alluvial formations consist chiefly of brown weathered tuff and tuffaceous sand, and gray-yellowish clays, sands, and gravels with pumice and tuff layers. All three show the effects of "pedalferization" (Bryan), suggestive of pluvial climates interrupted by intervening dry phases represented by their respective caliche soils. Three ancient beach deposits (El Risco 1-3) exist. In swamp deposits of El Risco age was found the skeleton of a mammoth hunter (Tepexpan Man) with numerous *Mammuthus imperator* remains in the same layer and 300 yards distant. A geophysical survey by Dr. Hans Lundberg aided in the discovery.

A few artifacts in the alluvium indicate the presence of Early Man in association with an Upper Pleistocene fauna. The Recent geologic history began with a dry climatic phase and caliche formation, followed by a Middle Recent moist phase, recorded by the Zacatenco beach and alluviation (Totolzingo). The pre-ceramic culture complex (Chalco) with basalt implements is assigned to these Early and Middle Recent substages. Two more recent terraces (Hondo and Remedios) contain ceramic remains of the Archaic and later cultures of pre-Spanish times.

The explorations were made possible by the Viking Fund of New York and carried out in co-operation with Mexican institutions and Professor Kirk Bryan.

ROLE OF ALUMINUM IN THE ROCK-FORMING SILICATES

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In the rock-forming silicates aluminum may appear in either eight-fold (octahedral) or four-fold (tetrahedral) co-ordination with oxygen. Octahedrally co-ordinated aluminum is structurally like magnesium or ferrous or ferric iron. Tetrahedrally co-ordinated aluminum is structurally like silicon.

A survey of the geologic distribution of tetrahedrally and octahedrally co-ordinated aluminum indicates that minerals containing tetrahedrally co-ordinated aluminum are characteristic of igneous rocks, thermally metamorphosed rocks, high-grade regionally metamorphosed rocks, and the product of artificial melts. Minerals containing octahedrally co-ordinated aluminum are characteristic of weathering products, sedimentary rocks, hydrothermal deposits, deuteric alterations, and low- and middle-grade regionally metamorphosed rocks (stress minerals). At high temperatures aluminum tends to be tetrahedrally co-ordinated and at low temperatures octahedrally co-ordinated. The effect of hydrostatic pressure is less obvious, but octahedral co-ordination is more economical of space.

The presence of other ions in a mineral, particularly the alkalis, seems to be important. In potassium-aluminum silicates there is always at least one tetrahedrally co-ordinated aluminum ion for each potassium ion present. The same holds true for the sodium-aluminum silicates except in the pyroxene, jadeite, and the corresponding amphibole, glaucophane.

Rock and mineral relationships considered in the light of aluminum co-ordination include kyanite-andalusite-sillimanite-mullite, epidote-plagioclase, and gabbro-eclogite. On the assumption that the linking of silicon tetrahedra is favored by low temperature and low pressure, and that high aluminum co-ordination is favored by low temperature and high pressure it is possible to derive, theoretically, mineral facies essentially similar to those of Eskola.

PYROSYNTHESES OF TELLURIDE MINERALS

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In connection with a comprehensive study of the telluride minerals an attempt was made to reproduce most of the established and reported species by fusing the powdered elements in the proper proportions in evacuated silica glass tubes. The following compositions gave practically homogeneous compounds which were proved to be identical with the corresponding minerals by microscopic and x-ray examination: $AuTe_2$ (calaverite), Ag_3AuTe_2 (petzite), Ag_2Te (hessite), Ag_5Te_3 or $Ag_{2-x}Te$ (empressite), Cu_5Te_3 or $Cu_{2-x}Te$ (weissite), Cu_4Te_3 or $Cu_{2-y}Te$ (rickardite), $NiTe_2$ (melonite), $FeTe_2$ (frohbergite), PbTe (altaite), HgTe (coloradoite), Bi_2Te_3 (tellurbismuth), BiTe or Bi_{2+x} Te_{2-x}(wehrlite). (Ag,Au) + Te ("muthmannite") gave $AuTe_2$ + Ag_3AuTe_2. Ag_4 + Te ("stuetzite") gave Ag_2Te + Ag_2. Pt + Te_3 ("niggliite") gave $PtTe_2$ + Te. Some natural tellurides dissociate on heating and cannot therefore be reproduced by fusion.

VICKSBURG OLIGOCENE FORAMINIFERA FROM MISSISSIPPI*

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From a composite of 37 samples from four stratigraphic sections in Rankin County, Miss., and 20 samples from the section at Mint Spring Bayou at Vicksburg, Miss., the smaller Foraminifera have been determined and their distribution plotted. They seem to constitute a single fauna with ecologic changes from shallow deposition in the lower beds to deeper-water deposition in the upper beds in some of the sections. The Foraminifera aid in marking the boundary between the Mint Spring marl member of the Marianna limestone and the overlying Glendon limestone member of the Byram formation. Correlation between the five sections is shown in a chart including the most significant species.

SUBMARINE TOPOGRAPHY OF THE MID ATLANTIC RIDGE

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During the summer of 1947 continuous fathometer records were taken from Woods Hole to Bermuda, from Bermuda over the Ridge to the Azores, and back from the Azores to the Ridge. From the Ridge back to Woods Hole the fathometer was recording only at depths of less than 1500 fathoms, but soundings were taken every half hour off the visual dial.

A survey was made of the North Easterly approaches to Bermuda and also of an isolated peak 150 miles to the northeast, but most of the surveying was performed in the area of the Ridge. Several small- and large-scale (1/364800) maps of the ocean bottom were made, with a contour interval of 100 fathoms for the latter. A study of these maps and of the correspon ding fathometer records shows a striking contrast between the high central backbone of the Ridge (between 1600 and 800 fathoms) having a width of 60 to 100 miles, and the adjacent foothills, which are characterized by a discrete series of repeatedly occurring terraces (between 2300 to 1600 fathoms), which are perfectly flat within the limits of instrumental error. The width of these terraced foothills on both sides of the Central Ridge is of the order of 150 to 200 miles.

The existence of a much deeper and wider (200 miles) flat stretch at 2890 fathoms, as well as of several intermediate levels on the way from Bermuda to the Ridge was noted.

The suggestion is made that these terraces may be indications of prolonged stands of a rising sea at levels close to those of these terraces or coastal plains.

The necessity for many more fathometer runs and the advantages of formation surveying are stressed.

SUB-ARCTIC SEDIMENTS IN THE GULF OF MEXICO

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Sediments characterized by a sub-Arctic fauna and many thin zones of fine-grained sand and silt are found within 1 or 2 feet of the surface of the sea floor over large areas in the Gulf of Mexico. In one place on the northern slope of Sigsbee Deep, 3 feet of sand is interspersed between two layers of

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blue mud at a depth of $33\frac{5}{16}$ inches below the sea bottom. Obviously the conditions of deposition of such sediments were markedly different from those now prevailing. The answers to these and other peculiar problems, such as the biohermlike character of some of the sea mounts near the edge of the continental shelf, are being sought in the study of the bottom cores and oceanographic samples collected by the ATLANTIS during its cruise of February and March 1947. This cruise was supported jointly by Woods Hole Oceanographic Institution and The Geological Society of America. Between the Atchafalaya River and the Rio Grande, some 550 stations were occupied. Twelve traverses were run across the shelf and seven traverses down the continental slope.

GEOLOGY OF THE MAINE COAST: FREEPORT TO FRIENDSHIP—THE MINOR PEGMATITES

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In the course of geologic studies of the Freeport-Friendship sector of the Maine coast, detailed observations and sketch maps on scales of 3 to 10 feet to the inch have been made of representative minor pegmatites in the hope that the beautifully exposed minor pegmatites will yield much that is applicable to the larger but less well exposed pegmatites. A very intimate association of aplitic and pegmatitic types is noteworthy. Aplite forms marginal facies, irregular patches, and central masses. Three structural types of pegmatite occurrence are: (1) pinch and swell, sill-like bodies or series of lenses, (2) fracture pattern networks, and (3) irregular bodies. Many of the lenticular masses have concentrations of quartz at the constriction of the lenses (corners of the eyes), and many have quartz veins normal to the trend of the sill which terminate at the contact. Many of the cross veins of quartz are localized by minor inward deflections of the contacts. Central, longitudinal quartz veins are also common. Foliation is prominent in many of the pegmatites. In part it is inherited from schists replaced by pegmatites, in part it is secondary, related to shearing. Streakiness and banding due to multiple intrusion, replacement, and possibly to primary flow are also present in many of the pegmatites. The present report is preliminary. Petrographic and areal studies both await completion.

THERMOGRAPHIC FEATURES OF SOME CARBONACEOUS SEDIMENTS

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A thermal method of analyzing and classifying the carbonaceous sediments is proposed wherein the sample is heated from room temperature to 1080°C at a uniform rate, and the variations in temperature at the center of the sample are measured with respect to its own surface or with respect to a similar but thermally inert sample experiencing the same treatment.

Results are presented which illustrate by sharp distinctions in the records the main classes of the coal series of sediments and by finer details of the graphs variations within a class. The naturally occurring liquid and solid hydrocarbons are shown to have distinctive thermographs which easily distinguish them from bituminous or coaly matter. Records from several oil shales and carbonaceous black shales exhibit type patterns which are easily recognized and are reliable for correlations indicating similarity of sedimentational environment.

Other applications of the thermographic method for studying sediments and minerals are noted, such as documenting the laterization process, identifying disorder, polymorphism, and exsolution in crystals, and studying isomorphism.

RECONNAISSANCE STUDY OF NEW ENGLAND MOUNTAIN GLACIATION*

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Field observations in the Rondane area of Norway showed that continental glaciation was preceded but not followed by local mountain glaciation and that the last continental ice sheet stagnated

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and disappeared by surface ablation. An attempt to apply this concept to the mountains of New England was not too successful. Features used as criteria in Norway and mentioned in the literature as occurring at several localities in New England were examined and found to be inconclusive.

The idea, however, is advanced tentatively for consideration and discussion, that there were at least two continental ice sheets in New England. The earlier covered the higher peaks and upland surfaces in the Mt. Katahdin area in Maine, the Presidential Range in New Hampshire, and the Adirondacks in New York and was probably much older than the Wisconsin stage. A younger ice sheet of Wisconsin age deposited fresh drift in the lowlands, but its erosional and depositional features also extend to the tops of the mountains on Mt. Desert Island, Maine, and to elevations at least above 2000 feet in the Catskill Mountains. Due consideration is given to faster physical weathering at higher than at lower elevations, especially above timberline.

NEW HYDROTHERMAL QUENCHING APPARATUS

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A simple apparatus has been developed for the study of equilibrium relations at high temperatures and pressures in mineral systems including volatile components. Investigations have been carried to pressures of 30,000 lbs. per sq. in. (approximately 4.5 miles depth) at temperatures up to 900°C. Results on the system K_2O—Al_2O_3—SiO_2—H_2O show that a water pressure of 15,000 lbs. per sq. in. lowers the liquidus about 100°C in the orthoclase field. In compositions approaching the quartz-orthoclase join a pressure of 30,000 lbs. per sq. in. gave relatively insignificant additional lowering.

DEVELOPMENT OF SOFT LAKE SUPERIOR IRON ORES FROM SILICATED IRON FORMATION

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Local metamorphism, probably of the hydrothermal type, adjacent to dikes, sills, quartz-adularia pegmatite veins, quartz-tourmaline veins, and quartz veins has induced secondary iron silicates such as grunerite, minnesotaite, and stilpnomelane to form at the expense of the primary minerals chert, siderite, and greenalite. The elimination of chert through silication is favored by an original high iron content of the rock, by primary textures which allow the reacting minerals to be in close proximity, by the formation of secondary low iron-high silica minerals, and by the introduction of iron.

Oxidation and partial leaching of either the original iron formation or the partially silicated phase produces the ordinary red or yellow cherty iron formation. The soft ores, both limonite and hematite, result from the oxidation and leaching of that phase in which the chert has been largely or completely silicated. Chert has not been removed as such, in the quantities hitherto considered necessary for the formation of ore.

INTERPRETATION OF AEROMAGNETIC SURVEYS

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It is assumed that certain types of large magnetic anomalies are due to prismatic blocks of magnetic material within the basement complex. The blocks have vertical sides and extend from the surface of the basement to very great depth. The polarization of these blocks is uniform, oriented in the direction of the earth's field, but is different in magnitude from the surrounding material.

Maps of the intensity and curvature of the magnetic field associated with such blocks are computed for a suite of block sizes at several latitudes. The curvature maps are examined for indications of maximum depth and block distribution. These indications are tested for reliability by comparing the computed maps with existing aeromagnetic maps of areas where basement depth is known from well-log information.

KARST TOPOGRAPHY IN THE KANSAS SUBSURFACE

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For a number of years evidence has been accumulating that karst topography is present in the subsurface of Kansas. Many test holes drilled for oil in Ellis, Russell, Barton, Rice, and Ellsworth counties have furnished data on the attitude of the Arbuckle dolomitic limestone of early Paleozoic age. They provide an accurate picture of a buried erosional surface showing the familiar characteristics of karst topography. One of the closely drilled areas in which information is especially abundant lies in southern Russell and northern Barton counties and involves the area of the Trapp pool. A detailed map of this area, covering approximately 50 miles square, reveals numerous sink holes as well as valley sinks and ravines.

The main part of the area is a nearly flat plateau of limestone at an altitude of approximately 1430 feet below sea level. The 20 or more sink holes range in depth from 20 feet to 168 feet. The opposite kind of topographic feature, the sharp butte or "needle," is also present. The highest one of these is 100 feet higher than the limestone in a sink less than a quarter of a mile away.

Narrow depressions resembling ravines or valley sinks are present within and on the periphery of the area. One of these ends in two deep "outlet sinks".

At least three other areas of similar size are known in the subsurface of western Kansas. On these some test holes have passed through the limestone into underground caverns and natural bridges. High spots on this karst topography yield oil, and low spots dry holes. Hence oil is related to topography and not structure.

ZONES IN THE VIOLA FORMATION OF WESTERN KANSAS

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Intensive study of samples from well cuttings now permit a tentative zonation of the Viola formation of western Kansas. The zones described are based upon lithologic characters and insoluble residues. Zone I is a cherty dolomite; the chert is dull white and opaque, and the dolomite is brown, finely crystalline, and chunky. It is found in Ottawa County typically developed and also occurs in Pawnee and northern Edwards counties. The thickness averages 35 feet. Zone II is a calcareous zone represented by coarsely crystalline limestone and brown lithographic limestone. In six counties it is represented by thick dolomites instead of limestones.

Zone III is a cherty dolomite in which the cherts are either white or mauve and waxy. This zone averages 50 feet in thickness.

Zone IV consists of coarsely crystalline limestones similar to those of zone II. They are brown and white spotted and often have additional colors. In Graham, Trego, Ness, and Kearny counties the rock is dolomitic instead of calcareous.

Zone V is a cherty dolomitic zone. The lithology is peculiar in that it is essentially a siliceous argillite in which small dolomite rhombs are scattered. A typical stony or smoky gray chert makes up about 40–60 per cent of the rock mass. This zone is the most distinctive one in the Viola sequence.

Zone VI consists of coarsely crystalline limestone in its typical aspect, but locally some lithographic limestone is present. This is especially the case in Ottawa and Osborne counties. Elsewhere it is likely to have three or four colors and almost always is sandy at the base (containing small rounded wind-blown grains). The thickness varies from 75 feet on the northeast side of the Barton Arch to an average of 20 feet on the southwestern side of the Arch. It is found in practically all counties in which Zone V occurs and usually marks the base of the Viola formation.

ENGINEERING GEOLOGY OF THE TUNNELS OF THE SAN DIEGO AQUEDUCT, CALIFORNIA

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Abnormal growth of the San Diego area during the war made it necessary to seek additional water supply. To meet the requirements, a 71.5-mile aqueduct has been constructed to carry water southward to San Diego from a diversion point on the Metropolitan Aqueduct which carries Colorado River water into Los Angeles. The San Diego Aqueduct consists chiefly of a large-diameter concrete pipe but includes seven tunnels ranging in length from 500 to 5700 feet.

The engineering geologic aspects of the aqueduct tunnels in all stages, from reconnaissance through construction, are presented. The surface and subsurface geology of the tunnels and the occurrence and handling of special geologic problems are discussed. Six of the tunnels lie entirely in Jurassic crystalline basement rock, and the seventh lies partly in crystalline rock and partly in soft Tertiary conglomerate. An extensive sample suite of rock types encountered in the tunnels was collected, and petrographic descriptions are given. Continuous cross sections showing the geologic structure and lithology, prepared as the tunnels were excavated, are included. Although the region contains very large, recently active faults, the tunnels, which lie in the intervening blocks, are relatively free from significant faulting. In these tunnels the rock types involved in the faulting rather than the magnitude of the faults governed the degree of construction difficulty presented.

Besides being of value to those in charge of operation and maintenance of the tunnels, the data presented should be useful during construction of future tunnels under similar conditions.

EROSION SURFACES AND THE UPLIFT OF THE ANDES NEAR LLALLAGUA, BOLIVIA

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The geomorphology of the Bolivian Andes is little known except from the rapid reconnaissances of a few students. The recurrent stages of uplift and erosion, and their dates are the subject of this paper. The Altiplano Basin, containing Lake Titicaca and the playa Lake Poopo, separate the Bolivian Andes into two distinct highlands, the Western and the Eastern Cordillera. The author carried on field work in the region about Llallagua, near the crest of the Eastern Cordillera, and approximately 155 miles south of the city of La Paz. Five recognizable erosion surfaces demonstrate an equal number of episodes of valley broadening which were separated by intervals during which the streams cut downward actively. The snow line of Pleistocene time must have been high because the mountain forms show little trace of glaciation, but terrace and stream-bed alluvium record at least two well-marked glacial stages. Minor forms suggest that the climate is now more arid than in the recent past. A combination of physiographic and paleontologic evidence leads to the conclusion that the uplift of the Andes began in the Late Pliocene and went on actively during the Pleistocene.

IOWAN TILL AT CHAMBERLAIN, SOUTH DAKOTA*

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The only pre-Wisconsin Pleistocene deposit identified in the vicinity of Chamberlain, South Dakota, is a clayey till, probably Kansan in age, which is deeply stained by chocolate- to purplish-brown oxides of manganese and iron. Overlying it is a till that resembles known Wisconsin tills of the region in being much stonier and sandier than the till of probable Kansan age. This younger till is overlain by loess regarded as of Iowan age. Post-depositional oxidation in the younger till is much less intense than in the older, a light yellow-brown mottling like that in the Iowan loess being the limit of its degree. However, this till includes blocks of the old, stained till, and in some of these the staining appears to be smeared out, indicating reworking subsequent to the intense oxidation. This evidence is believed to indicate a considerable time interval between the two tills, and the younger is therefore believed to be Wisconsin. This fact and the stratigraphic relation to the loess require that the younger till be assigned to the Iowan. The drift thus assigned is largely graded and drained and differs in topographic expression from a later (Tazewell?) drift that occurs a few miles to the east.

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AGE AND SUBDIVISIONS OF THE ROCKY MOUNTAIN FORMATION AT BANFF, ALBERTA

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The Rocky Mountain formation, the uppermost unit of the Paleozoic sequence in the Canadian Rockies, is composed of dolomite, sandstone, quartzites, and chert. The age of the formation has been considered to be Pennsylvanian or Permian, or both. In this communication the writer considers it advisable to divide the Rocky Mountain formation in the Banff area into two members: the lower consisting principally of dolomite and sandstone with chert nodules and probably of Pennsylvanian age; the upper, consisting of dolomite, bedded chert, phosphatic shale and a thin phosphate bed which is probably Permian in age.

CHIMAEROID FOSSIL EGG CAPSULES FROM ALBERTA

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In this communication a new species of chimaeroid egg capsule is described, and its stratigraphic horizon is discussed.

PARTLY VITRIFIED XENOLITHS IN PILLOW BASALT*

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Pillow basalt in the Tuya Range of northern British Columbia contains many xenoliths of granite and a few of quartzite. The feldspar and quartz of the granite inclusions are highly crackled and, together, have yielded abundant colorless glass with a refractive index of 1.495. Some of the feldspar grains which have been partly vitrified are cut by glass veinlets that form extremely fine meshworks. The ferromagnesian minerals have been converted almost completely to a dark-brown glass containing scattered new crystals of clinopyroxene and black opaque minerals. A small proportion of the quartz contains tridymite in minute veinlets of glass. The quartzite inclusions show partial vitrifaction, some introduction of basic pale-brown glass chiefly along grain boundaries, and the formation of sanidine, cordierite, hypersthene, and clinopyroxene. A fragment of granite in basaltic agglomerate is also partly vitrified and contains the new minerals clinopyroxene and anorthoclase. The temperatures attained by the xenoliths did not exceed 1075°C but were probably greater than 900°C.

GEOLOGY OF THE NORTHERN FLANK OF THE WIND RIVER MOUNTAINS, WYOMING

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The area here considered covers approximately 100 square miles in northwestern Fremont County, Wyoming, between Jakey's Fork on the east and Sheridan Creek on the west. Both are northeast-flowing streams which enter Wind River.

All Paleozoic systems except the Silurian are represented in the 2625 feet of sediments present. The Paleozoic sediments dip away from the pre-Cambrian core of the Wind River Mountains, and under the Mesozoic and Tertiary strata of the Wind River Basin to the north and east. Eroded remnants of nearly horizontal Tertiary sediments lie on Paleozoic rocks well up on the flanks of the Wind River Mountains.

* Published with the permission of the Chief Mining Engineer, British Columbia Department of Mines.

The major faults in the area are normal with maximum displacement of approximately 1000 feet. Downthrown blocks are to the north of the approximately east-west trending faults, and to the west of the north-south striking faults. One large north-south trending fault in the eastern part of the area is an exception—the downthrown block is on the east. Fault planes are nearly vertical. Sharply infolded sediments of Cambrian and Ordovician age are found in the pre-Cambrian crystallines. Hot springs which have deposited large masses of travertine in the area were associated with weakened zones caused by the folding and faulting. Three, or possibly four, phases of the Laramide orogeny are apparent. The folding of the Paleozoics occurred in late Cretaceous time, followed by tensional forces producing the faulting. Eocene tilting is evident in the Tertiary sediments.

ROCK ALTERATION ASSOCIATED WITH THERMAL SPRINGS

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The study of rock alteration and its relation to ore-bearing solutions can be approached in a number of different ways. Each general method is examined briefly, and the need for a close integration of all methods is emphasized.

The study of processes taking place in areas of thermal springs is one approach. In such areas there is opportunity to investigate several specific types of alteration as well as the physical state, temperature, composition, and concentration of each associated solution. General conditions at Steamboat Springs, Nevada, are described; rocks above the general water table are being altered by sulfuric acid resulting from the oxidation of H_2S, and rocks below the water table are being more slowly attacked by the saline spring waters. Outstanding studies are summarized.

TWO TILLS AND THE DEVELOPMENT OF GLACIAL DRAINAGE, STAFFORD SPRINGS, CONNECTICUT

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Glacial features along the upper Willimantic River valley were mapped in the vicinity of Stafford Springs, Connecticut. Till in the area can be separated lithologically and stratigraphically into two types. An iron-stained, brown, compact clayey till, having in places a reddish-brown, cemented, and oxidized zone, is overlain by a younger, gray, loose, sandy till. Two localities of the younger till overlying the older, with the cemented zone between, are described. The differences in cementation and weathering of the two tills are considered possible evidence of multiple glaciation.

Glacial-fluvial features are correlated stratigraphically, morphologically, and lithologically with successive retreatal positions of a wasting ice lobe. Detailed development of four kame terraces is presented. These demonstrate that, as the ice lobe melted downward and retreated, outliers of stagnant ice masses were stranded at its margin.

SILICIFIED ORDOVICIAN TRILOBITES

HARRY B. WHITTINGTON

Limestones of lower Edinburg (lower middle Ordovician) age in the neighborhood of Strasburg, Virginia, contain silicified trilobites at many horizons. Preparation of this material by dissolving the limestone with hydrochloric acid was begun by G. Arthur Cooper in 1938. The writer is now studying these specimens, with other material furnished by the U. S. National Museum but prepared at the University of Birmingham, England. This work was made possible by a grant to Cooper from The Geological Society of America that enabled the writer to come to Washington to study the fragile material. The grant also made possible field examination of the trilobite-bearing beds, the collection of additional material, and comparisons with previously described species from the Appalachians. Forty species belonging to 35 genera have been recognized, of which at least 15 are new. Agnostids,

harpids, trinucleids, raphiophorids, remopleurids, styginids, asaphids, illaenids, otarionids, proetids, odontopleurids, encrinurids, phacopids, and cheirurids are represented, in addition to new genera of uncertain affinities.

Complete or partially articulated tests of these trilobites are very rare, the various parts—cranidium, free cheeks, hypostoma, segments, pygidium—usuallly being dissociated. Growth stages from a very small size, degree 1 or degree 2, of all the species are represented, and six types of protaspids occur. In most cases it has been possible to associate the separated parts of the adult of each species and to identify the growth stages. The perfection of the silicification enables the morphology of both dorsal and ventral surfaces to be studied and illustrated in detail, and particularly the ornamentation, articulation, and appendifers. The developmental stages of most of the genera have not previously been described.

Comparatively little is known of trilobites of this age in the Appalachians. Description of these species will not only increase our knowledge of trilobite morphology and development, but will be a considerable aid in the refinement of stratigraphy. At least 12 of the genera in the collection also occur in European faunas. The new genera are principally odontopleurids, proetids, and encrinurids, which families are little known from described faunas of this age.

FORAMINIFERA FROM THE UPPER CRETACEOUS BOYNE BEDS OF MANITOBA AND RELATED FORMATIONS

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About 60 species of Foraminifera have been found in the Boyne member of the Vermilion River formation in Southern Manitoba. The microfauna shows close relationship to that described from the Niobrara of Nebraska. Calcareous forms make up most of the fauna, and species of *Gumbelina* and *Globergerina* are numerous. In some beds the latter are practically the only types of Foraminifera. The richest fauna occurs near the base of the member. Some species have a limited range, and it is possible to differentiate about three general zones.

The very rich fauna in Canada is found only in the southern part of Manitoba where the member is mostly a gray calcareous shale or impure limestone that weathers to cream. Elsewhere the rock is mostly a medium- to dark-gray calcareous shale speckled with white. The fauna in these areas has fewer species, and the specimens are smaller. The equivalent beds can be traced north to near the limits of the Cretaceous in the southern Plains, across the Plains to the Athabaska River, and as far west as the edge of the Foothills in southern Alberta.

ISOTOPE RATIOS, A CLUE TO THE AGE OF CERTAIN MARINE SEDIMENTS

FRANS E. WICKMAN

If an element A has a radiogenic isotope A_1 and a nonradiogenic A_2, the ratio A_1/A_2 is an index of the age of marine chemical sediments, if the content of the isotope B^* producing A_1 can be neglected. It is shown that the method can be used for strontium (and perhaps Pb^{208}) on limestone and anhydrites.

TRIASSIC OF THE DELAWARE VALLEY

BRADFORD WILLARD, DEAN B. MCLAUGHLIN, J. DONALD RYAN

Lehigh University; University of Michigan; Lehigh University

Between Easton, Pennsylvania, and Trenton, New Jersey, the southeastward-flowing Delaware River traverses the Newark series along a 30-mile section nearly perpendicular to the strike. The continental Newark series, of Upper Triassic age, is resolved into three formations:

Brunswick red sandstone and shale and local fanglomerates
Lockatong argillite
Stockton conglomerate, arkose, and red beds.

The series has suffered local alterations adjacent to basic dikes and sills. Many exposures along both sides of the Delaware Valley furnished data for a fairly complete section of the entire series, its structures, and relations to adjacent, overlying, and underlying formations. The studies of the area have yielded many details hitherto unrecognized or not fully recorded. Of particular significance are the interbedding of red and gray strata in the transition zone between the Lockatong and the Brunswick formations and new data on the thicknesses of all three formations.

PERMIAN ROCKS OF THE UPPER YUKON REGION, ALASKA*

JAMES STEELE WILLIAMS

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The Permian sequence of rocks exposed along the Yukon River between Circle and Eagle is compared with that studied along the upper White River, a tributary to the Yukon, near Russell Glacier, and with the Permian section measured near Lake Menkomen in the Copper River area. Tentative correlations between the three areas are given, and preliminary correlations with well-known Permian rocks in the United States are discussed. It is thought that all the rocks included in the Permian of the upper Yukon region are younger than Wolfcamp. Studies of the invertebrate faunas of these rocks are under way.

GEOLOGICAL HISTORY OF CHURCHILL, MANITOBA

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The story begins with the deposition of ill-sorted sand and scattered quartzite pebbles, presumably in late pre-Cambrian time. Uplift, erosion, and warping, in undetermined order, preceded late Ordovician time, when a shallow sea transgressed the area. Later Paleozoic and Mesozoic history is unknown. Tertiary uplift and erosion determined the course of the river and the harbor basin. Depression during the ice age, and shallow-water deposition as the ice made its final retreat, is recorded in beaches and a *Saxicava-Pecten* fauna. Ice movements from various sources have left an intricate pattern of striae. Postglacial uplift is of the order of 400 feet. Movements within historical time are negligible.

DIRECTION OF GLACIATION IN DISTRICT OF KEEWATIN, NORTHWEST TERRITORY

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The direction of latest glaciation shows plainly on many air photographs of northern Canada. These directions have been plotted from oblique photographs taken of strips along the Thelon and Dubawnt Rivers in the District of Keewatin, N. W. T. Additional directions of glaciation observed from airplanes and directions of striae read on the ground during the journey by Exercise Musk ox from Churchill to Cambridge Bay via Baker Lake have also been mapped. All agree in suggesting that the ice fanned out from the direction of Hudson Bay or Labrador across District of Keewatin. There is no new evidence to support the old hypothesis that there was a center of glaciation in Keewatin,—indeed many of the old observations on striae have only to be turned through 180° in order to agree with the later observations.

GEOLOGICAL AND GEOPHYSICAL STUDY OF A PART OF THE CANADIAN SHIELD

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By informal co-operation between the Geological Survey of Canada, Dominion Observatory, Ontario Department of Mines, and University of Toronto the study of a triangular area lying across the Ontario-Quebec boundary and including Sudbury, Timmins, and Val d'Or has been started with the

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object of learning the structure, tectonics, and physical properties in three dimensions of this well-studied part of the Canadian Shield.

The problem is being tackled in several ways. The geology is being recompiled and combined with information obtained from vertical air photographs. A series of traverses have been made with vertical magnetometers and with gravimeters. About 1000 determinations of the radioactivity of rocks in the area have been made, and 800 more are contemplated. Temperature gradients, thermal conductivities, and heat flows have been measured in three mines to about 7000 feet depth. Determinations of the thicknesses and properties of crustal layers are in progress by recording earthquakes and rockbursts upon specially arranged seismographs.

USE OF AIR PHOTOGRAPHS TO INTERPRET THE STRUCTURE OF PART OF THE CANADIAN SHIELD

J. TUZO WILSON

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The scarps and linear topographic features of an area of about 80,000 square miles in the District of Mackenzie, N. W. T., were plotted from oblique air photographs. The resulting pattern when combined with faults discovered during field work by the writer and by many others shows that there are many large, late pre-Cambrian faults there which can possibly be interpreted as being due to a single set of orogenic forces. A preliminary attempt was then made to obtain similar information in other parts of the Canadian Shield using only topographical and geological maps. This approach has been checked in another area of 10,000 square miles by a detailed study of the vertical air photographs and a recompilation of the geology between Sudbury and Kirkland Lake, Ontario. This paper describes the methods used and the results so far obtained.

MARINE TERRACES OF THE COAST OF LEBANON

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Marine terraces along a narrow coastal plain separate the rugged Lebanon Mountains from the eastern shore of the Mediterranean Sea. The inner margins of the terraces have average elevations of about 95 m, 65 m, 45 m, 15 m, and 6 m above sea level. They are cut on tilted Cretaceous and Tertiary limestones and bear a thin and patchy veneer of marine conglomerate.

The consistency of the elevations for 250 km along the coasts of Lebanon and Syria indicates that the terraces represent eustatic marine transgressions during the Quaternary interglacial stages. Evidence for regressions of the sea during the glacial stages comes from the ancient coastal sand dunes and red soils which partially cover the marine terraces and extend below the present sea level along the shore. Fluvial deposits from the larger mountain streams also locally cover the marine terraces and interfinger with the eolian deposits, indicating that pluvial stages (excessive rainfall and denudation in the mountains and deposition on the piedmont) were contemporaneous with glacial stages (low sea level and extensive eolian deposition).

Tentative correlations of the younger terraces and deposits assign the 45 m transgression to a pre-Riss interglacial, the following definite regression to the Riss glacial, the 15 m and 6 m terraces to the Riss-Würm interglacial, and the following regression (to −6m at least) to the Würm glacial. The final transgression to present sea level is equivalent to the Flandrian transgression of western Europe.

The marine, eolian, fluvial, colluvial, and soil deposits associated with the lower terraces provide a firm basis for correlating prehistoric cultures of the Middle East with the basic glacial chronology of Europe.

STABILITY RELATIONS OF GROSSULARITE

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Experiments of an exploratory nature have been conducted to determine the range of stability of grossularite garnet, $Ca_3Al_2(SiO_4)_3$. The following techniques were applied: thermal and differential

thermal analysis, high-pressure and temperature bombs, hydrothermal bombs, and powder metallurgical sintering techniques. Natural grossularite decomposes in the solid state into gehlenite, wollastonite, and anorthite between 1000° C. and 1100° C. The three resulting minerals are essentially a eutectic mixture below 1265° C. Using both synthetic and natural materials, the decomposition products were found to be stable at least as low as 800° C. This result is dependent on the variables in the diffusion process. The P-T diagram indicating the range of stability of grossularite in the system $CaO\text{-}Al_2O_3\text{-}SiO_2$ has been derived theoretically and determined in part experimentally. The decomposition products are stable above 1028° C. at pressures up to 4100 atmospheres. The nature of the substitution solid solution series $Ca_3Al_2(OH)_{12}\text{-}Ca_3Al_2(SiO_4)_3$, in which the minerals grossularite, plazolite, hibschite, grossularoid, and hydrogrossular occur, is confirmed. An irreversible, endothermic reaction takes place in "pure" natural grossularites in the vicinity of 1000° C. This is thought to be the release of the hydroxyl groups as water; the more hydroxyl, the lower the temperature of release. It is recommended that all garnets be analyzed for H_2O^+. Although grossularite may form at high pressures in dry systems, its hydrothermal nature should be emphasized.

ABSTRACTS OF PAPERS PRESENTED AT MEETING AT STANFORD UNIVERSITY, CALIFORNIA, APRIL 11–12, 1947

Cordilleran Section of the Geological Society

DRAINAGE OF UPPER TWIN LAKE, FRESNO COUNTY, CALIFORNIA

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Upper Twin Lake is a small shallow rock-bottom lake on the north side of Kaiser Ridge at an elevation of 8500 feet. The lake basin is of glacial origin and is formed principally in granitic rocks of the Sierra Nevada batholith but is margined on the north by a marble roof pendant. At normal lake level the lake water flows into a sinkhole in the marble and reappears as a spring at an elevation 50 feet lower and 1000 feet from the sink. Few small sinks not exceeding 10 feet in depth occupy an abandoned, shallow, surface sluiceway across the marble outcrop.

The site of the lake basin and adjacent area was covered with glacier ice. The weathered condition of the erratics and moraine and the absence of glacier polish suggest the late Tahoe or early Tioga age of the glacier formerly occupying this area.

The writer believes that during the time glacier ice occupied the Twin Lake basin there was little or no subterranean drainage. The melt water from the ice crossed the marble roof pendant as subglacial and as surface drainage. The creation of the lake and the initiation of its subsurface drainage occurred in late Tahoe or early Tioga time.

STATUS OF TOPOGRAPHIC AND GEOLOGIC MAPPING IN OREGON IN 1946*

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Study of geology in Oregon has been handicapped by a lack of adequate topographic base maps. Only 30 per cent of the State has been mapped on a scale of 1:125,000, and 14 per cent on a scale of 1:62,500. Mapping on the latter scale is restricted largely to northwestern Oregon. By dividing Oregon into quadrants with the lines of 44° latitude and 122° longitude, the relative areas mapped (in per cent) may be estimated as follows:

Quadrant	*15′ quadrangles*	*30′ quadrangles*	*Not mapped*
Northwestern Oregon	73	17	10
Southwestern Oregon	18	48	34
Northeastern Oregon	4	46	50
Southeastern Oregon	0	10	90

The State Department of Geology and Mineral Industries has published nine geologic maps on a scale of 1:96,750 since 1938. The area mapped is about 6861 square miles. Geologic maps on a scale of 1:125,000 by this and other agencies cover 4830 square miles. These, together with other small areas on larger scales, total less than 20 per cent of the State.

Unpublished geologic maps or geologic mapping in progress account for a total of nearly 10,000 square miles. Three agencies have completed manuscripts on or are working in 19 areas in the State as follows:

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Agency	Number of areas	Square miles
U. S. Geological Survey	7	4847
Oregon State College	6	2784
State Dept. G.M.I.	5	2341

Maps on smaller scales for mineral, water-supply, and general reconnaissance surveys cover an additional 55 per cent of the State. More than 24,000 square miles or 25 per cent of the State has not been examined.

ASH FALLS IN PLUVIAL FORT ROCK LAKE

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Three layers of volcanic ash occur in the uppermost 12 feet of lacustrine sediments in the Fossil Lake area of pluvial Fort Rock Lake, Lake County, Oregon. The earliest contains abundant flakes of biotite. The associated beds are mostly sands. Minor disconformities and differences in distribution of the beds in a small area indicate fluctuations in a shoaling lake. Next earlier beds consist mainly of pumiceous sands which have supplied most of the fossils of the Fossil Lake fauna.

These three ash falls, attributed to Newberry Volcano or its subsidiaries, are recorded in the Summer Lake basin also, where a crystal-rich pumice layer next preceding the biotite-bearing ash is assigned (Allison) to the climactic eruption of Mount Mazama on the site of Crater Lake (Williams). Although other pumice beds are known, a correlative of the Mount Mazama pumice layer in an undisturbed position of its fall has not yet been identified with certainty in the lake sediments of the Fort Rock-Christmas Lake Valley. As exposures are limited to deflation basins, it may be concealed. However, most of pluvial Fort Rock Lake either was already too shallow to preserve the primary fall or reworked the material as the lake level went down. The Fossil Lake area was lower than most of the remainder of the lake bed, and so a shallow remnant persisted there through the final waning stages beyond the time of the last ash falls.

PLIOCENE ENVIRONMENTS OF THE GREAT BASIN

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Twenty later Tertiary floras distributed from southern Oregon and Idaho to southeastern California and northwestern Arizona provide data for reconstruction of environments over the region now desert. Lower Pliocene floras from the northern Great Basin are dominated by forest (Sierra-Cascade and Rocky Mountain affinity), with subordinate woodland and chaparral. At the same time central Nevada had dominant oak-juniper woodland and chaparral, with forest in a minor role. In the Mohave region, Lower Pliocene floras include oak and conifer (pinyon) woodland, chaparral, and arid subtropical scrub.

Ecological requirements of related living plants suggest a biseasonal yearly rainfall which ranged from 20 to 25 inches over the lowlands at the north, totalled 15 to 20 inches in central Nevada, and averaged 10 (or less ?) to 15 inches in the western Mohave area. Temperatures were moderate at the north, with frosts frequent in winter. To the south, summer temperatures were higher, and winters were milder, with frosts largely absent in the Mohave area.

By Middle Pliocene time, as rainfall was lowered some 5 inches over the lowlands, trees of Lower Pliocene woodland and montane associations were restricted largely to upland areas. Adjacent plains were now dominated by grassland and semidesert shrubs, and hardy riparian trees occupied stream banks and lake borders. These data suggest that the Great Basin and Mohave Desert floras (*sensu* Shreve) are no older than late Pliocene.

APPLICATIONS OF THE NIGGLI-BECKE PROJECTION FOR ROCK ANALYSES

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Chemical and modal analyses of igneous, sedimentary, and metamorphic rocks are represented on ordinary graph paper as points in the Niggli-Becke quaternary chemical system of rock classification. The components of the system are al (alumina), fm (iron and magnesium oxides), c (lime), and alk (alkalies). Silica values (si) are plotted as ordinates against the quaternary system.

Graphically outstanding among the petrographic relationships are the different distribution fields of the igneous and sedimentary rocks, the four igneous areas in the si diagram (quartz-bearing rocks, quartz-free feldspathic rocks, feldspathoid-bearing rocks, and ultra-femic and theralitic rocks), and the chemical transfers involved in metamorphic and weathering processes.

SILL-LIKE INTRUSIONS IN THE CENTRAL COAST RANGE OF OREGON*

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Remnants of sills and sill-like bodies as much as 750 feet and commonly 300 to 500 feet in thickness cap most of the peaks and plateaus in the central Coast Range of Oregon. Marys Peak, Fanno Ridge, Laurel Mountain, Saddleback Mountain, and Mt. Hebo are outstanding examples. Although many of the intrusives are true sills, some appear to be discordant with the underlying strata. Where the sills have been removed by erosion, feeder dikes form prominent ridges and also constrictions in the stream valleys.

Most of the sills intrude middle or upper Eocene sediments. Oligocene and younger sediments are generally absent from the central part of the Coast Range. However, near the coast in a few places sills of this stage of intrusion penetrate beds probably of Keasey age (uppermost Eocene or lowermost Oligocene). The upper age limit is as yet undetermined. The sills were gently folded, and in a few places faulted, during late Tertiary arching of the Coast Range.

Petrographic examination by Dr. W. D. Lowry showed that most of the intrusives are quartz-bearing gabbros, including granophyric gabbro. They are not related to the quartz-free feeders of the middle Miocene Columbia River basalt.

GEOLOGY OF THE METHOW QUADRANGLE, WASHINGTON

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The U.S.G.S. topographic sheet of the Methow quadrangle, Washington, covering an area of 812 square miles, includes a part of the eastern flank of the northern Cascade Range as well as a part of the western Okanogan Mountains. The northern limit of the quadrangle lies 35 miles south of the Canadian border. The relief of the area is approximately 7700 feet.

Andesitic breccias, flows, and interbedded sediments conformably overlie approximately 2500 feet of greenish-gray arkose containing Upper Cretaceous fossil plants. These beds overlie approximately 16,000 feet of black siltstones, graywackes, and silica pebble conglomerates containing marine Cretaceous fossils at the base of the section. Unconformably beneath the marine beds there is a folded and faulted but relatively unmetamorphosed section of black shales, graywackes, and bedded metavolcanics and breccias of lower Mesozoic(?) age. The oldest rocks mapped are paragneisses, amphibolitic schists, quartzites, and granitoid gneiss which are in fault contact with the younger sedimentary rocks.

Granitoid rocks of the Chelan batholith have invaded all of the sedimentary and metamorphic

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rocks described. The batholith occupies approximately the southwestern third of the quadrangle. Small stocks of granitic and quartz diorite rocks of the Okanogan batholith invade the metamorphic and graywacke series along the eastern boundary of the area mapped.

The Cretaceous rocks of the northwestern part of the quadrangle are folded in northwestern-southeastern trending anticlines and synclines characteristic of northern Cascade structure. Normal and reverse faults both parallel and transverse to the folding complicate the structural picture.

PSEUDO-BEDDING STRUCTURES IN A BANDED GABBRO*

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In the Tungsten Hills near Bishop, California, "angular unconformities", "cross-bedding", and penecontemporaneous faults, all on hand-specimen scale, occur in a banded gabbro. The banding is caused by rhythmic alternation of felsic layers (dominantly labradorite) with dark layers (mainly labradorite; hornblende, part of which is uralitic and encloses occasional remnants of augite; and magnetite). A later near-by intrusion of quartz monzonite probably induced the formation of uralite. Most unconformities are marked by heavy dark layers. The faults contain hornblende. Minor minerals include sphene, apatite, epidote, albite, chlorite, biotite, bastite, and talc (or muscovite).

Although the banding dips 65°–75°, it may originally have been less steep. The labradorite crystals have both linear and planar preferred orientations. The 010 plane is subparallel with the banding. The *a* axes are closely aligned. The average length of the labradorite crystals is smallest just above an "unconformity" and increases upward through several layers. In any dark layer the average labradorite crystal is usually longer than in the contiguous felsic layers.

Of the several hypotheses advanced by students of banded rocks, rhythmic differential settling of continuously forming crystals, in combination with flow by intrusion or convection, seems most satisfactorily to explain the banding. Auto-intrusion apparently has been operative locally. *Lit-par-lit* injection, partial assimilation of inclusions, intrusion of an inhomogeneous magma, rhythmic intrusions, and rhythmic crystallization do not seem applicable to this gabbro.

RECESSIONAL MORAINES IN MOUNTAIN VALLEYS

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In well-glaciated mountain ranges, such as the Sierra Nevada in California, each canyon commonly reveals a series of low recessional moraine loops enclosing a lake or a lake plain. It is significant that the number of these moraines varies widely in valleys in the same range, without apparent reason, and also that each series is confined between the lake and the terminal moraine. To explain these conditions it is suggested that the wastage of such a glacier reduced its thickness, as well as its length, to such an extent that it was severed near the middle, leaving the still active part of the glacier above and a body of stagnant ice below. The point of separation is the first important rock step in the bottom of the valley upstream from the lake. After this stage in the dwindling of the ice was reached, no more moraines could be built, except very small ones above the rock step.

LATERITIC ORE OF ALUMINUM IN THE GREATER ANTILLES*

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Much of the surficial red earth of Jamaica is an aluminous laterite with a sufficient available alumina content to be of commercial interest. The laterite forms extensive blanket deposits on the

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early Tertiary limestone, with the thickest deposits in depressions of the karst topography. A residual origin is indicated, though the purity of the limestone bedrock offers a difficulty to such an interpretation.

Less extensive deposits of similar laterite are known in Hispanola, but only red clay has been found under comparable conditions in Cuba.

FLUVIAL SURFACES OFFSET BY FAULTING NEAR PASADENA, CALIFORNIA

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Pleistocene stream gravels, alluvial cone surfaces, and lower stream terraces have been dislocated vertically and tilted backward by movements on two of the four important east-west faults traversing the Pasadena area.

QUESTION ON CORRELATION OF CONTINENTAL TERTIARY DEPOSITS

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How far can we go in assigning plant-bearing beds from several adjacent Tertiary basins to the same stratigraphic unit? This has been done with unfortunate results in the case of the Auriferous gravels of the Sierra Nevada, now known to represent deposits ranging in age from Middle Eocene to Pleistocene; there is reason to believe that the Puget group and the Kenai formation may likewise represent more than a single series of the Tertiary system.

This question has arisen during the study of the Mascall and other Miocene floras from the Columbia Plateau in Oregon. All of them occur in diatomaceous ash associated with Columbia lava, and they include many critical species in common. May they be properly considered to represent florules of the Mascall flora?

THE CONE AS AN EROSIONAL FORM

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Cones are generally regarded as typically volcanic in origin. The author has been struck by the large number of cones not of volcanic origin occurring in the arid and semiarid regions of southwestern United States. These cones are composed of various types of rocks: lake sediments, volcanic ash, metamorphics, granite. They range in size from a few feet to more than 100 feet in height, and their diameters vary accordingly. The shape likewise varies, from the true, symmetrical, sharp-peaked cone to the somewhat rounded mound, and there are all gradations between the cone and the ridge.

It is the writer's opinion that the cone is a fundamental erosional form, developed under arid and semiarid conditions of climate in any type of homogeneous rock, consolidated or unconsolidated, where structure either is lacking (*i.e.*, massive) or neutral (*i.e.*, horizontal). There is some suggestion in the literature that similar forms may develop under humid conditions as well.

TRANSPORTATION OF SEDIMENTS IN THE SEA BY CURRENTS

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Clastic debris in the sea is moved about by several different types of oceanic currents until it eventually reaches a site of permanent deposition. The mechanics of the current types and the environments of their most effective operation are briefly reviewed.

Near the coast, longshore currents, generated by breakers approaching the beach at an angle, are chiefly responsible for the movement of beach material parallel to the shore. Their strength is mainly a function of the breaker height, size of angle of wave approach, wave period, and beach slope. Rip currents (seaward-moving streams caused principally by the escape of inshore accumulations of water brought about by meeting longshore currents and the gradual mass transport of water by wave action) tend to move material seaward from the beach. An opposite process is the shoreward bottom creep caused by oscillatory wave motion. The surf zone is characterized by high velocity currents with great turbulence.

On the continental shelf tidal currents and horizontal eddies from the permanent oceanic currents are most important. Beyond the outer edge of the continental shelf, tidal currents, and perhaps currents due to internal waves, probably play the chief role in the distribution of sediment.

Other types of currents are briefly discussed: salinity, wind drift, density, thermal, and those due to seiches and tsunamis.

STRONTIUM DEPOSITS OF SOUTHERN CALIFORNIA*

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Strontianite occurs as beds and concretions in upper Tertiary tuffs and clays in the Mud Hills, near Barstow. Celestite occurs as concretions and beds in sandy clay and gypsum of upper Tertiary age in the Avawatz and Fish Creek mountains, and in clay and tuff of upper Tertiary age near Ludlow. Celestite concretions are present in sandy gypsiferous clays of recent age in Bristol Dry Lake.

Tuffs and lavas are associated with the deposits at Mud Hills, Ludlow, and Bristol Dry Lake. Gypsum is present at the others, and salt is also present at Avawatz Mountains and Bristol Dry Lake.

At Mud Hills the stronianite is controlled by faults and fractures and is therefore believed to be post-sedimentary.

At Ludlow the celestite is closely associated in time and space with hydrothermal vein deposits of barite and manganese oxides.

The deposit at Ludlow contains at least 1,140,000 tons of celestite per 50 feet of depth and may have contained before erosion as much as 100,000,000 tons of celestite. The other deposits are small.

The strontium could have been derived by weathering of the surrounding rocks, and concentrated by evaporation. This is unlikely for the very large Ludlow deposit, since it is not associated with salt and gypsum. A hydrothermal origin is favored because three deposits are associated with igneous activity, one is associated with hydrothermal veins, and one is evidently post sedimentary.

ROCK UNITS OF THE SOUTHERN CALIFORNIA BATHOLITH AS EXPOSED IN THE CUYAMACA PEAK QUADRANGLE*

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One of the problems encountered in mapping an area in a complex batholith is the determination of practicable rock units. The Cuyamaca Peak quadrangle in San Diego County is a representative area in the Southern California batholith and affords an ideal locality for the study and mapping of that igneous body.

The area is underlain by Triassic (?) metasediments (Julian schist), now in the form of septa and pendants, which have been repeatedly intruded by plutonic rocks. The oldest of the intrusives is the Jurassic (?) Stonewall granodiorite, which has injected and locally "granitized" the older schists. An Upper Cretaceous sequence of intrusive igneous rocks, ranging from early olivine gabbros through quartz diorite, granodiorite, and granite to late aplite and granite pegmatite cuts the older rocks.

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The rock units making up the igneous complex are characterized by distinctive topographic expression, individual outcrop form, and primary flow structures as well as by their petrographic properties. All these factors have been considered in determining the component mappable formations of the batholith. The easily recognized planar primary structures bring out, when mapped, a structural fabric in most of the rock units, especially the quartz diorites and granodiorites. The manner in which the structural fabric of some of the rock units is cut across by that of others is a valuable aid in working out the intrusive sequence.

SUBSIDENCE IN THE LONG BEACH HARBOR AREA, CALIFORNIA

JAMES GILLULY AND U. S. GRANT

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Precise releveling at intervals since 1928 demonstrates that subsidence of a few tenths of a foot has taken place over a wide area in the southern part of the Los Angeles plain. Within a much more restricted area, centering in, and coincident with, the Wilmington oil field, the subsidence during the same period has amounted to as much as 5 feet. The isobases are in large part parallel with the field outlines.

Experimental data on compressibility of the oil sands, in conjunction with isopachs of the several oil zones and data on the pressure decline that has occurred within the oil sands during the period of field development, indicate that compression of the oil sands can account for the entire subsidence. It is unnecessary to attribute the subsidence to tectonic factors, though these cannot be positively excluded; and there are reasons to doubt the efficacy of shale compaction brought about by decreased water pressure. Shifting of surface load, withdrawal of oil, lowering of the water table and dewatering of shallow or deep aquifers can all be shown to be quantitatively inadequate to explain the subsidence. It is accordingly concluded that the subsidence is almost wholly due to decline of hydrostatic pressure within the oil sands which has brought about an increase in the effective weight of the superincumbent strata. The observed subsidence is proportionate to the theoretical vertical shortening of the oil sands under this hypothesis.

The mechanics involved probably apply equally to most other examples of subsidence in oil fields.

XENOLITHS AND SKIALITHS

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Inclusions in rocks have been classified in different ways and have been salient factors in various petrogenetic interpretations. Field examinations of several localities coupled with petrographic studies of large, lantern-slide-sized thin sections have indicated to the writer that inclusions fall into two groups similar in appearance but differing in microtextures and structures.

The term xenolith should be restricted to its original meaning—namely, inclusions definitely foreign to enclosing igneous rocks. In certain localities it may be useful to distinguish between xenoliths that have travelled a long distance (hypoxenoliths) and those evidently derived from the adjoining wall rock (epixenoliths). Autoliths have a method of origin similar to xenoliths but represent an earlier phase of the magma.

These dislodged, rafted, or travelled types of fragments need to be distinguished from the static relics that occur in rocks of metasomatic origin. Skialith (*σκιά* = shadow, *λίθος* = rock) is suggested as a name for inclusions in metasomatic rocks. Skialiths may contain porphyroblasts similar to crystals in the matrix, and they commonly exhibit ragged boundaries characterized by crystalloblastic intergrowths.

From a petrogenetic standpoint xenoliths may be indicative of piecemeal stoping or may give information as to the character of the wall rocks at depth. Reaction effects if present may aid in the solution of the difficult problem of differentiation, or give some clue as to the temperature of the magma. The range of skialiths from relics showing but little change to mere shadows of the original rock may offer cogent evidence of complex metasomatic processes and metamorphic differentiation.

SEISMICITY OF THE EARTH

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Previous results are revised and extended. Most of the former conclusions are notably strengthened. Over 2000 shallow shocks and about 1000 deep-focus shocks are located. Magnitudes of deep shocks are assigned for the first time. Ninety-two great earthquakes (magnitudes $7\frac{3}{4}$ or over) have been identified for 1904–1945, and 334 major shocks (7.0 to 7.7) for 1918–1945. Geographical results are presented in a new set of maps.

The earth's surface consists of relatively inactive blocks separated by narrow active zones. The largest such block is the Pacific stable mass; each of the others includes a continental stable shield. The highest seismicity is associated with folding and thrusting in the structural arcs of the circum-Pacific belt. Those of the Alpide belt are less active. Both belts include sectors where the dominant processes now are block faulting and horizontal shearing. In other seismic belts these are the principal processes; active arcs are absent. The remarkable repetition of earthquakes from nearly the same hypocenters under the Hindu Kush (depths about 230 km.) and the Carpathians (depths 100–150 km) suggests exceptional local conditions.

CHRONOLOGY OF POSTGLACIAL VOLCANIC ACTIVITY IN OREGON AND WASHINGTON

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The chronology of volcanic glass and pumice strata interbedded in many peat bogs in the Pacific Northwest has been determined indirectly by pollen profiles from the peat sections. The postglacial climatic trends interpreted from the pollen profiles and correlated with chronological data from several sources provide a basis for segregating the Postglacial into a series of time intervals. The stratigraphic position of the volcanic ejecta in relation to the climatic stages serves to date both relatively and approximately some of the volcanic activity. The eruption of Mount Mazama, which formed the caldera holding Crater Lake, occurred about 10,000 years ago, or before the warm, dry period of 8000 to 4000 years ago. The position of Newberry pumice above Crater Lake pumice in Summer Lake basin of south-central Oregon reveals that Newberry Crater erupted after Mount Mazama, but before the late Wisconsin lakes had become entirely desiccated. It is dated between 9000 and 8000 years ago. The stratigraphic position of a layer of volcanic ash in Washington peat columns, attributed to Glacier Peak, suggests that the eruption took place about 6000 years ago. A pumice stratum in peat sections of the northern Willamette Valley is believed to have come from Mount St. Helens and is dated at about 5000 years. The most recent volcanic activity recorded in peat sections that were analyzed was that of Devil's Hill in the Three Sisters region, and it is dated at about 4000 years.

STRATIGRAPHIC AND STRUCTURAL FEATURES OF THE IVANPAH QUADRANGLE, CALIF.-NEVADA

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The following conclusions concerning this area of about 4000 square miles in southeastern California and Nevada are based upon about 25 months' field work between 1921 and 1934. The region records almost uninterrupted sedimentation during Paleozoic and Mesozoic time. Before this, there was sedimentation (Pahrump Series, about 5000 feet thick) upon a crystalline basement (Archean). Paleozoic sediments attained a maximum of 16,000 feet along the western border; the average on the eastern border is 8000 feet. Mesozoic sediments average 4500 feet. The Tertiary section of sediments and lava flows attains a maximum of 5000 feet and appears to be wholly late Miocene or early Pliocene.

Two major orogenies are recorded by thrust faults and normal faults. The first (Laramide, late

Cretaceous or early Tertiary) includes at least five major thrust faults along which early Paleozoic rocks generally rest upon upper Paleozoic or early Mesozoic rocks. Great masses of quartz monzonite were intruded toward the close of the epoch, and there was widespread mineralization. It was followed by profound erosion from early Eocene to late Miocene time. The second orogeny (early Pliocene) followed the period of mid-Tertiary sedimentation and vulcanism. It is represented by a single great thrust fault, remnants of the upper plate of which have been mapped over an area of 20 by 30 miles. The thrust fault was followed by normal faults and local sediments.

FOOTHILL COPPER-ZINC BELT OF THE SIERRA NEVADA, CALIF.*

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The Foothill copper-zinc belt, in the foothills of the Sierra Nevada, has produced about 195,000,000 pounds of copper, 30,500,000 pounds of zinc, appreciable gold and silver, and a little lead.

The rocks of this belt fall into two major categories—a complex of faulted and folded Paleozoic and Jurassic metavolcanic and metasedimentary strata, invaded by a variety of intrusions; and a sequence of flat-lying or low-dipping Tertiary and Quaternary volcanic and sedimentary deposits unconformably overlying the older series.

The copper and zinc deposits, developed within the older group of rocks, for the most part are lenticular sulphide bodies formed by replacement along zones of faulting, shearing, and crushing. With few exceptions, they are associated with zones of sericitization, silicification, pyritization, or chloritization, superimposed on the metamorphic rocks by hydrothermal action.

The deposits are characterized by abundant pyrite (less commonly, pyrrhotite) associated with chalcopyrite, generally with sphalerite, and some gold and silver. On the basis of primary mineral content they are classified into four types.

Structural control of ore deposition is evident in many deposits, and particularly significant features are intersections or bifurcations of faults and shear zones, changes in strike or dip of faults irregularities on contacts between rocks of markedly different competency, and intersections of faults with such contacts.

Field evidence indicates the ore was introduced after the regional orogeny, concomitant metamorphism, and emplacement of the granodiorite. Spatial distribution of the deposits suggests they are genetically related to the Sierra Nevada batholith.

MOUND AND DEPRESSION TOPOGRAPHY OF THE CENTRAL VALLEY OF CALIFORNIA AND OTHER AREAS

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Mound and depression topography is a characteristic feature of the Central Valley of California, other Pacific Coast areas, the Southern Mid-Western States and of some areas on other continents. In the Central Valley it occurs in areas characterized by old soils and is considered to be a more or less normal result of soil development under certain physical conditions. Climatic conditions vary within rather wide limits. Youthful, mature, and old-age stages of development have been recognized.

In all occurrences seen by the authors, the mounds and depressions are so similar that similar origins seem certain. The formative processes are those of erosion working on certain types of materials. The authors subscribe to two modes of origin for this type of topography.

(1) Surface erosion by water under conditions of exterior drainage on relatively gentle slopes, which are underlain by a thin layer of soft material, below which there is a more resistant layer.

(2) Surface erosion under conditions of interior drainage on flat or gently sloping areas, which are underlain by relatively thin layers of soft material, below which are substrata of more resistant

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permeable materials. These substrata must be sufficiently thick and permeable to permit downward seepage of rain water carrying in suspension particles entrained at the surface.

PREGLACIAL AGGRADATION OF MCKENZIE RIVER, OREGON

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Two hundred feet of fluvial sand and gravel unconformably overlies pre-Pliocene Western Cascade extrusives and underlies Pliocene High Cascade basalt at the lower end of Foley Ridge southeast of McKenzie Bridge in sec. 24, T. 16 S., R. 5 E., WM. The basalt is intercalated with and overlain by volcanic conglomerate. A still higher section of gravels 300 to 400 feet thick overlies the basalt 6 miles farther east on the south canyon wall above Lost Creek Ranch.

Corresponding high terrace deposits exist for 15 miles along the upper McKenzie River valley below McKenzie Bridge but have not been found farther west down the valley. High terrace gravels along the lower valley are thought to have been removed by erosion.

The McKenzie River was aggraded by addition of volcanic debris to the stream load, probably during a general Willamette-Puget trough aggradation epoch which produced the Troutdale formation of Pliocene-Pleistocene age.

The major portion of the high terrace gravel was deposited prior to glacial times.

DONNER PASS ZONE OF DEFORMATION, SIERRA NEVADA, CALIFORNIA

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The trough extending north from Tahoe, past Donner Lake, is bounded on the west by a zone of uplift in which the contact of Tertiary andesitic deposits on the eroded surface of the basement complex is from 800 to 2400 feet higher than in adjacent parts of the depression. This paper deals with a part of the zone extending from Donner Pass 10 miles S.10° E. to Squaw Peak. In this stretch there are two areas of maximum uplift that are due to folding and faulting of the east limbs of the folds. The faults with greatest throw dip east at high angles, but notable movements occurred on west-dipping and vertical faults, and, on some faults, the dip changes from east to west in passing along the strike. Deformation began with folding of the entire zone. This was then accentuated, with accompanying faulting, to produce the two structural highs. Finally there was major faulting along the east edge of the zone. All of this deformation is believed to be post-Miocene and preglacial. The evidence from this region gives no support to the idea that the Tertiary deposits of the Sierra Nevada were deformed merely by westward tilting of a rigid block.

INTERNAL STRUCTURE OF THE PALA PEGMATITES, SAN DIEGO COUNTY, CALIFORNIA*

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Most of the Pala pegmatites are dikes that dip gently to moderately westward in hornblende gabbro. Although they split, bulge, or pinch out abruptly in some places, their general structure is rather simple. Their internal structure, in contrast, is much more complex.

Some of the dikes consist almost wholly of graphic granite, whereas others comprise both graphic granite and a strikingly layered rock rich in fine-grained albite and quartz, with or without garnet or schorl. Pockety concentrations of lithium-tourmaline, spodumene, beryl, and numerous other accessory minerals occur in the central parts of some dikes, where they probably were formed by replacement of pre-existing pegmatite. Schaller has described all these features.

Thin pods and lenses of massive quartz with large crystals of perthite form inconspicuous cores

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and core segments in many dikes, and the margins of these inner zones appear to have localized the development of most of the gem-bearing pockets. A few thick dikes, notably the Stewart, are zoned much like the Harding pegmatite of northern New Mexico. Cores of massive quartz with long, thin spodumene laths are surrounded successively by units of (1) massive quartz, (2) massive quartz with large perthite crystals, (3) coarse, blocky perthite, and (4) graphic granite. Superimposed upon the zones and zonal structure are large replacement bodies of lepidolite and lepidolite-albite pegmatite, as well as numerous fracture fillings and rare-mineral pockets. Most of the replacement phenomena are confined to the lower, or footwall, halves of the pegmatite bodies.

JOINT PATTERNS IN THE THREE PEAKS LACCOLITH, IRON SPRINGS DISTRICT, UTAH*

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Indirect evidence indicates that the Tertiary monzonitic intrusives around which the Southern Utah iron deposits occur are laccoliths, but the presence of large replacement ore bodies around the distal margins of small floored intrusives raises a question as to the origin of the mineralizing emanations and led to mapping of igneous structures in the Three Peaks laccolith.

Primary flow structures are weak, but primary fractures, especially cross joints, are strongly developed. The cross joints of the principal set are essentially vertical, radiate outward from a focus concealed by alluvium, and strike normal to the contact. Additional sets strike approximately parallel with the contact and dip normal to it; these indipping cross joints are limited to areas where the intrusive contact is sharply flexed in section. The radial set indicates radial outward spreading of magma in a flat sill-like body at the horizon of intrusion; concentric sets indicate local yielding of roof and lateral margins by arching that produced the final laccolithic form.

Except in a thin shell and a core area, the cross joints carry magnetite fissure veins from a small fraction of an inch to 20 feet in thickness. These taper inward and downward toward the core, where the joints are tight and barren. The barren roots of the cross-joint veins are exposed so widely as to preclude the possibility that the vein matter was derived from a deep-seated source. Field relations and cogent chemical data indicate that the mineralizing emanations originated in the laccolith.

STRATIGRAPHY OF THE CERRO GORDO AREA, INYO COUNTY, CALIFORNIA*

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Sedimentary rocks of the southern Inyo Mountains at Cerro Gordo range in age from lower Ordovician (Pogonip) to Triassic. A moderate degree of alteration has locally obliterated organic remains. The beds are in the main highly folded and sheared, with dips on the flanks of the range usually exceeding 60°. Overturning and isoclinal relations are recognized.

Northwesterly faults striking roughly with the mountain axis divide the region into stratigraphic and structural units. In the central or summit area the section extends from Pogonip on the east flank to Permian on the west slope without known major discontinuity. Toward the east base Pogonip limestone with overlying quartzite (probably Eureka) and Silurian dolomite are faulted against Lower Carboniferous plant-bearing shales. On the west slope an important fault separates Triassic volcanics from a belt of Carboniferous shales and limes, the latter locally intruded by aplitic bodies with hornfelsic alteration of bordering limes. Nearly vertical Pogonip, Eureka quartzite, and Silurian dolomites exposed along the rugged lower west slopes are in possible reverse-fault contact to the east with black shales and limes believed to be Lower Carboniferous.

Pennsylvanian and Permian limestones are subdivided on the basis of fusulinid zones.

The important ore bodies at the Cerro Gordo mine occurred in Devonian marble on the east side

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of a northerly trending fault zone separating these rocks from Lower Carboniferous black shales and Pennsylvanian silicated limes.

LOWER CAMBRIAN PLEOSPONGIA FROM THE PURCELL RANGE OF BRITISH COLUMBIA

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During the summer of 1946 the author collected pleosponges (Archaeocyathi) from the Lower Cambrian Donald formation in the Dogtooth Mountains, Purcell Range, of British Columbia. These fossils are described and illustrated. The collection contains representatives of 16 species, 10 of which are new.

The pleosponges occur in association with *Olenellus*, *Kutorgina*, *Rustella*, and other typical Lower Cambrian fossils. The fauna indicates a closer relationship to the Asiatic and Australian forms, rather than the pleosponges of Waucoba Canyon-Silver Peak region of California and Nevada.

PERMAFROST AND GEOMORPHOLOGY IN THE LOWER YUKON RIVER VALLEY*

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Permafrost, or permanently frozen ground, in the flood plain of the Lower Yukon River is correlated with the geomorphic features of the terrain.

The Yukon flood plain near Galena, Alaska, is about 10 miles wide and is characterized by swamps, lakes, sloughs, and streams. The plain has four geomorphic phases, and each phase has distinctive permafrost characteristics. The term phase refers to the temporary appearance of the surface features produced by a meander during the planation of the valley. The most important criteria which enable one to differentiate these phases are: (1) change in the drainage pattern as the result of the alteration of the meander lakes, (2) change in vegetation, (3) depth to permafrost.

The characteristics of the four phases are as follows. Phase one (the youngest): youthful drainage pattern, large deciduous tress, and low permafrost table. Phase two: youthful drainage pattern, large coniferous trees, and slightly higher permafrost level. Phase three: mature drainage pattern, small coniferous trees and tundra, and high permafrost table. Phase four: old-age drainage pattern, much tundra, and a high permafrost table.

As the river moves from side to side in the valley, it acts as a thawing agent and lowers the permafrost table. When the river meander advances, the permafrost rises into the newly deposited sediments. The rise of the permafrost over the years causes the change in vegetation.

BLUE AGATE OF LEAD PIPE SPRINGS, SAN BERNARDINO COUNTY, CALIFORNIA

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Blue chalcedony in a red rhyolite porphyry matrix from the extreme northwestern corner of San Bernardino County constitutes an outstanding collector's item. It was formerly known in Southern California as "Cal-Azur".

The igneous rocks of this region have been mapped as "Miocene volcanics".

Thin sections reveal the presence of five silica minerals: high quartz, tridymite, chalcedony, low quartz, and opal. Some of the low quartz is pseudomorphous after tridymite.

A chemical analysis of the chalcedony shows 98.76 per cent of SiO_2 and 0.86 per cent H_2O. Arguments are advanced in favor of the idea that chalcedony is a distinctive mineral and not merely a variety of quartz.

Remarkable pseudomorphs of chalcendony after calcite are found here.

The agate occurs in part in spherulites, the so-called "thunder-eggs".

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WILLAMETTE FLOOD SITUATION

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The Willamette and its upstream tributaries, of which the well-known McKenzie is the principal one, have caused more or less serious floods from the time of white occupation of the valley. Actually this river has been at or above bank full stage 80 times in the past 47 years, and once in every 5 years has exceeded flood stage by 10 feet. The worst flood on record occurred in 1861, and the last in December 1946.

In this paper the geologic history of the river is briefly discussed, and the special geologic conditions are pointed out.

Various proposals for controlling the river are given and reasons for the present program stated. The U. S. Army Engineers have adopted the plan of upstream dams and propose to erect seven of these; two of the smaller ones are already constructed. The two already constructed, Fern Ridge on the Long Tom and the Cottage Grove dam on the Coast Fork of the Willamette, in the 1943 and 1945 floods have fully justified the expenditure on them.

Due to the presence of much tuffaceous material and deep weathering under very humid conditions in this region, special problems have confronted the engineers.

The cities of Eugene and Springfield, owing to their sites close to the river, are constantly and seriously menaced. The situation at present is critical until the construction of the remaining dams is expedited.

UNUSUAL OCCURRENCE OF ILSEMANNITE

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Ilsemannite, a rare molybdenum mineral of uncertain composition, is found at the Kiggins mine on the Oak Fork of the Clackamas River in Clackamas County, Oregon. The writer corroborated his identification of the mineral by microchemical and X-ray methods. The ilsemmanite is similar in appearance and behavior to that first described by Höfer from Bleiberg, Germany, and also that studied by Hess from Ouray, Utah.

The ilsemannite occurs in a strong, nearly vertical calcite vein, and in places the blue color has worked into the cleavage of the clear calcite. Halotrichite usually covers the ilsemannite, and the separation of the two minerals is very difficult. Of the dozen or more known occurrences of ilsemannite throughout the world, this one is unique in being associated with cinnabar, which is found at the Kiggins mine in commercial quantities. The cinnabar is one of the last minerals to have been deposited, and well-defined veinlets of it cut across most of the other minerals in the deposit.

TUSCAN FORMATION OF NORTHERN CALIFORNIA NEAR RED BLUFF*

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Exploration of the Iron Canyon dam site near Red Bluff, California, by the Sacramento District, Corps of Engineers, War Department, in 1945 and 1946 permitted detailed study of the Tuscan formation in the northwestern part of the Tehama quadrangle and the southwestern part of the Tuscan Buttes quadrangle. The Tuscan formation has been subdivided into five members. The youngest is the Sacramento tuff and sand member, underlain in turn by the Iron Canyon agglomerate, the Seven-Mile tuff and sand, the Bald Hill agglomerate, and the Supan tuff and sand members. The axes of two anticlines, three synclines, and one monocline have a general southwest trend and plunge in that direction at a low angle. One axis has a northwest trend. These structures are very gentle and they represent minor warping of a regional syncline. Faulting is of minor importance.

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STATUS OF THE GLAUCOPHANE SCHIST FACIES

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In 1929 Eskola proposed a glaucophane schist facies, thereby implying special physical conditions for development of mineral assemblages containing glaucophane. According to Eskola's latest available statement (*Entstehung der Gesteine*, 1939, p. 345) these conditions are: very high pressure (comparable with the eclogite facies); moderate temperatures (equivalent to amphibolite and epidote amphibolite facies). This paper reviews evidence for and against recognition of a separate glaucophane schist facies. Admittedly there are certain striking mineralogical analogies between glaucophane schists and eclogites. But close association of albite, muscovite, chlorite, calcite, epidote minerals, pumpellyite, and actinolite with glaucophane is interpreted as evidence of low-temperature low-pressure origin; so also is constant association of glaucophane schists with metamorphic rocks typical of the greenschist and epidote amphibolite facies. In some regions (*e.g.*, California) soda-iron metasomatism of rocks bordering ultrabasic intrusives has been demonstrated as an essential factor in formation of glaucophane schists. Elsewhere the parent rocks (basic lavas or intrusives) seem to have contained sufficient soda, and soda metasomatism has probably been slight. It is suggested that the chemical condition necessary for development of glaucophane schists is high concentration of certain ions (Na and Fe and perhaps Al) in pore solutions active during metamorphism. This would also explain simultaneous development of jadeite-bearing pyroxenes in some glaucophane schists, and in some cases rocks properly classed as eclogites. Physically the glaucophane schist facies seems to be equivalent to the greenschist and epidote amphibolite facies. Derivation of glaucophane rocks directly from eclogites is interpreted as retrogressive metamorphism.

A CRITIQUE OF THE TIME-STRATIGRAPHIC CONCEPT

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The Bright Angel group of the southern Great Basin region is defined as consisting of the predominantly argillaceous strata which lie between the underlying Prospect Mountain quartzite and overlying Middle Cambrian limestones. This lithogenetic unit ranges in age from partly pre-Cambrian in the Nopah Range of southeastern California to entirely Middle Cambrian in the Grand Canyon of northern Arizona. The Bright Angel group is employed to illustrate the fact that the problems of stratigraphic classification are four-dimensional and, as such, are not amenable to treatment by the conventional dual system of stratigraphic nomenclature.

The fact that rock units and unconformities may vary in age from place to place is determined as the sole factor demanding (1) a three-fold nomenclatural system, and (2) abandonment of the concept that erosional breaks may serve as time-stratigraphic boundaries. This variation in age of lithogenetic units is recognized as a fundamental truth in stratigraphy, equal in significance to the laws of superposition and faunal succession, and is appropriately designated, therefore, as the principle of temporal transgression.

STRUCTURE OF THE NORTHEAST PART OF THE TEJON QUADRANGLE, CALIF.*

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The structure of the western part of the Tehachapi Range is dominated by two major northeast-trending faults, ½ to 1½ miles apart, which are traceable for more than 20 miles along the center of the range. They delimit a band of albite-chlorite schist and interbedded fine quartzite, separating it from the injection gneiss and garnet-bearing diorite to the northwest and from granite and marble

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to the southeast. The faults are marked by crush zones 10–100 feet wide. Within the area mappde the south fault contains lenses of schistose graphitic marble, from 2 to 200 feet wide. The areal and vertical distribution of the igneous and metamorphic rocks suggests that at least the south fault had a large horizontal component to its movement, although the direction of this movement cannot be told.

Smaller faults of similar trend and steep dips are on both flanks of the range and extend southward across the Antelope Valley to the San Andreas rift. Low scarps along two of these faults indicate Pleistocene or Recent movement.

Volcanic flows and tuffs, overlain by Miocene sediments, occupy the south and west margins of the Antelope Valley and are bounded on the south by the San Andreas rift. Within a zone about 3 miles wide immediately adjacent to the rift, these rocks have been thrown into tight steeply pitching folds, locally overturned, and broken by low-angle faults of small displacement. The general direction of the overturning has been toward the north, away from the San Andreas rift.

GEOLOGY OF THE REGION AROUND PARICUTIN, MEXICO*

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The oldest rocks exposed *in situ* in the Parícutin region are gabbros, probably coeval with the quartz monzonites found among the ejecta of the new volcano. Presumably they are of early Tertiary age. Resting on them is a thick series of andesitic lavas, mudflow breccias, tuffs, and tuffaceous sediments, with subordinate sheets of welded rhyolite tuff, olivine basalt, and hornblende andesite that lie horizontally or almost so. These probably underlie Parícutin itself at shallow depth.

Following a long interval of erosion, the huge volcano of Tancitaro Mountain was built to the southwest of Parícutin, chiefly by quiet effusions of pyroxene andesite. Judging by the degree of erosion, it is of late Pliocene and/or early Pleistocene age.

During the remainder of Pleistocene time and subsequently scores of large lava cones and hundreds of smaller cinder cones rose to dominate the landscape of Michoacan. Chemical and microscopic analyses show that their products are not so uniform as previously supposed. While olivine basalts and olivine-bearing basaltic andesites predominante by far, many volcanoes and several isolated flows erupted during the last few thousand years consist of pyroxene andesite. No regular trend of differentiation has been discerned. The lavas now being discharged are olivine-bearing basaltic andesites essentially similar to the majority of the late Pleistocene and Recent flows of the region. Most of the young volcanoes are arranged without order; a few are alined northeast-southwest, parallel to the principal fissure zone at Parícutin itself.

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Pacific Coast Branch of Paleontological Society

UPPER PALEOZOIC AND TRIASSIC FROM THE CONFUSION RANGE, WEST-CENTRAL UTAH

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The Confusion Range is between the House Range on the east and the Snake Range of Nevada on the west. It is a folded mountain range which has been maturely dissected into hogbacks and strike valleys.

The stratigraphic section includes an estimated 17,000 feet of sedimentary rocks ranging from Ordovician to Lower Triassic. The pre-Mississippian, about 4200 feet thick, is largely dolomitic limestone with a 300-foot white quartzite probably equivalent to the Eureka of eastern Nevada. The Mississippian, 1825 feet thick, contains a fauna strikingly comparable to that of the typical Mississippi Valley section. Abundant *Platycrinus bozemanensis* and *Cactocrinus arnoldi* characterize the Upper Kinderhook. *Productus crawfordsvillensis*, *Productus viminalis*, and *Spirifer logani* typify the Keokuk. *Agassizocrinus conicus*, *Leiorhynchus carboniferum*, *Lyrogoniatites newsomi*, and *Neoglyphioceras subcirculare* are distinctive of the fossil zone correlated with the Moorefield of Oklahoma. The rich and varied Chester is typified by *Cleiothyridina sublamellosa*, *Diaphragmus elegans*, *Dictyclostus inflatus*, *Punctospirifer transversa*, and *Triplophyllum spinulosum*. The Pennsylvanian, 1600 feet thick, carries *Juresania nebrascensis*, *Spirifer occidentalis*, *Rhipidomella penniana*, *Hustedia mormoni*, and *Campophyllum nevadense* in the fossiliferous lower portion, and horizons with *Chaetetes* colonies higher up. The Permian, 8500 feet thick, carries a typical *Punctospirifer pulcher* fauna in the upper ,limestone portion, but the lower, sandy facies is essentially nonfossiliferous. *Schubertella kingi*, *Pseudoschwagerina*, and *Schwagerina* horizons are correlated with the highest Oquirrh in the Wasatch Mountains. The Triassic, 903 feet thick, contains *Inyoites oweni*, *Meekoceras muschbachanum*, *Xenodiscus nivalis*, and *Juvenites dieneri* as representatives of a rich ammonite zone.

BATHYMETRIC DISTRIBUTION OF GASTROPOD GENERA

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Nearly 12,000 occurrence records representing 964 "generic" units have been compiled from about 1600 different localities from all oceans. The records have been segregated according to three surface climatic zones: Arctic (below 5°C.), Temperate (5° to 20°C.), and Tropical (above 20°C.). The collecting stations represent all depths down to slightly over 7000 meters. Four genera have been recorded from depths between 5000 and 5500 meters, but none deeper. The greatest concentration of gastropods occurs in depths of less than 200 meters, but the present data indicate a secondary population concentration between 1100 and 1400 meters which apparently cannot be accounted for by the distribution of the samples. Of the 964 "generic" units recorded, 26 are confined to the Arctic zone, 211 to the Temperate zone, and 384 to the Tropical zone. Inasmuch as the climatic zones are based on surface temperatures, the significance of this distribution is uncertain. The records for each "generic" unit have been segregated according to climatic zones, and the maximum, minimum and, median depths for each zone indicated. Twenty genera are represented by over 100 records, while 34 genera are represented by 50 to 99 records. About 70 genera appear to be commonly indicative of depths of less than 10 meters.

GROWTH STAGES OF SOME SIMPLE CORALS

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Detailed study of attached simple corals shows that the record of the various stages of growth of the individuals is preserved in the corallum, principally in the base. Two principal modes of growth are found: one where the corallum is formed by simple conical enlargement of the prototheca; the other where several successive concentric embryonic thecal walls are secreted before the adult corallum is formed by conical enlargement of the post-embryonic thecal wall. *Caryophyllia* and *Cyathoceras* normally have the first type of development, while *Balanophyllia*, *Paracyathus*, and *Astrangia* characteristically show the second type of development.

NUCLEAR WHORLS OF HEMINAUTILUS ETHERINGTONI DURHAM

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In the course of describing *Heminautilus etheringtoni* from the Aptian of Colombia the author figured and described a medium longitudinal section of the early whorls of this species. In the specimen available at that time the end of the siphuncle appeared to open into the umbilical perforation, with no evidence of abrasion or recrystallization to account for the connection. Because of the possible importance of this observation a topotype of the species was obtained and sectioned for confirmation. In this second specimen the end of the siphuncle definitely does not open into the umbilical perforation but terminates about midway in the first chamber, a condition in accordance with that observed in other nautiloids.

GENERA OF SYRINGOPOROID CORALS AND THEIR RELATIONSHIPS

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Present tendencies are to divide *Syringopora* into numerous genera on the basis of growth habit, mural processes, wall thickness, nature of tabulae, presence or absence of septa or septal spines, and presence or absence of a central tube. Unfortunately, terminology of morphologic features is not standardized; hence, descriptions of some genera are very misleading. Most typical material is foreign and unavailable, and many references are difficult to obtain. This summary study is offered so that a ready reference to syringoporoid genera will be available. Illustrations and descriptions have been restudied to determine the limits of the syringoporoid genera. A diagnosis of each genus and a description and figure of each genotype are given. For the sake of completeness the relationships of the syringoporoids to each other and to *Aulopora* and to *Cladochonus* [=*Monilopora*] are reviewed. Genera principally involved are *Syringopora* [=*Harmodites*], *Multithecopora*, *Hayasakia* [=*Tetrapora*], *Kueichowpora*, *Ceratopora*, *Roemeria*, *Labyrinthites*, *Syringolithes*, *Vaughanites*, and *Drymopora*.

VARIATIONS IN SYNONYMIES

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A synonymy is a compilation of the systematic names by which a category of organisms has been recognized. Organization of a synonymy is governed only by rules laid down by editors and by personal preference; hence, published synonymies are highly variable in form and content. Even so, they naturally fall into two main groups: the "chronological" form arranged by dates, and the "alphabetical" form arranged by names. The chronological form may be divided into the "name-date" and the "date-name" types, depending upon the sequence of elements cited. The alphabetical form may be divided into the "segregated" and the "grouped" types, depending upon whether individual citations are on separate lines with the name repeated each time, or are grouped together in paragraphs with all references to each variation in name listed after that variation. Aside from its purely taxonomic function, the synonymy can be a source of information on geographic and geologic distribution. Omission of synonymies is a source of considerable mental anguish to later workers. Occasionally, the faunal sections of exhaustive stratigraphic papers are based in part upon material previously identified as questionable, as "sp.", or erroneously referred to some other species, yet there will be no mention of these facts in synonymies. It should be the duty of the systematist to include synonymies in his work or at least to give a reference to a recent complete synonymy. Otherwise, he willfully leaves the stultifying part of the work for subsequent students to do for him.

CARNIVORES OF THE BLACK HAWK RANCH FAUNA

J. R. MACDONALD

Museum of Paleontology, University of California, Berkeley, Calif.

The Carnivora in the Black Hawk Ranch fauna are represented by *Vulpes, Aelurodon, Osteoborus, Bassariscus, Pseudaelurus*, and fragmentary remains of Mustelinae, Procyoninae, and Machairodontinae. The fauna is found in a rich pocket of Lower Pliocene stream sediments on the south slopes of Mount Diablo, Contra Costa County, California. A small flora consisting of mesic flood plain and woodland-chaparral components is found interbedded with the mammalian remains.

ORIGIN OF THE PELECYPOD FAMILY GLYCYMERIDAE

DAVID NICOL

Stanford University, California

The Glycymeridae arose from a cucullaeid stock probably during Late Jurassic time. A study of the morphologic characters of both familes proves that they are remarkably similar, particularly when Early Cretaceous species are considered. The chronogenetic evidence also confirms the data shown by the morphologic characters. If only mature specimens are examined, the hinge teeth of the two families appear unrelated. A young cucullaeid, however, goes through a stage of tooth development which is like that of the Glycymeridae.

ARTICULATED SKELETON AND SKIN IMPRESSION OF A CAPITOSAURID LABYRINTHODONT

FRANK E. PEABODY

Museum of Paleontology, University of California, Berkeley, Calif.

In the Museum of Paleontology of the University of California is a unique skeleton of a capitosaurid from the Lower Triassic Moenkopi formation of Arizona. It was found by the 1941 field party in the subgypsum Moenkopi of Moqui Wash, 5 miles west of Winslow. The fine-grained, ripple-marked sandstone which contained the specimen is approximately 80 feet above the base of the formation in a zone which has produced numerous skulls of other capitosaurids. Near the skeleton and at the same level occur capitosaur-like amphibian footprints.

The skeleton lies in a natural position, body curved slightly to the left, limbs outstretched. Part of the skull is gone, but the postcranial skeleton is intact. Conchoidal fractures in the hard sandstone have exposed parts of all the skeleton except the left fore limb. Individual bones of the postcranial skeleton are separated from each other by gaps representing the former position of cartilage. Tarsus and carpus were completely cartilagenous. The fractures, which have tended to follow planes determined by the flattened body, disclose not only the skeleton but skin impressions as well. The dorsal region and both hind limbs, including the digits, are partly outlined. The skin impressions are probably continuous; they appear as a dark film studded with small ossicles of bone.

NEW ELASMOSAUR FROM THE UPPER CRETACEOUS OF TEXAS

ELLIS W. SHULER AND S. P. WELLES

Southern Methodist University, Dallas, Texas; University of California

A new elasmosaur from the uppermost Eagle Ford Cretaceous of Dallas, Texas, is now in the Department of Geology, Southern Methodist University, Dallas, Texas. The specimen consists of a skull, complete neck, and pectrum. The skull is damaged but uncrushed, with most of the sutures clearly defined. The pectrum has a well-developed median bar, as in *Elasmosaurus platyurus* Cope, and coracoids with narrow shafts and broadly expanded distal extremities.

This skeleton is the first from North America to combine uncrushed skull, neck, and pectrum, and is therefore the key to the previously described mid-continent forms which have been based upon partial skeletons.

A co-operative paper will be published in which Dean E. W. Shuler will describe the general stratigraphy and petrology of the locality, Dr. Claude C. Albritton, Jr., will describe the associated invertebrates, Dr. Arthur Richards will describe the petrography of the gastroliths, and the authors will describe the osteology and relationships of the plesiosaur.

SILURIAN OF THE KLAMATH MOUNTAIN PROVINCE

BURTON J. WESTMAN

Etna, Siskiyou County, California

Collections made from 1944 to 1946 in southeastern Siskiyou County, California, prove that the Silurian exists in the Klamath Mountain Province.

Previously the nearest Silurian was recognized in the northern Sierra Nevada, and the oldest Klamath faunas were considered Devonian until C. W. Merriam collected brachiopod and trilobite faunas near a Devonian locality 3½ miles southwest of Gazelle which were with little doubt Silurian.

This paper deals primarily with a Silurian fauna found in numerous isolated limestone outcrops which rest upon or are included in the intrusive complex of the foothills on the southeast side of Plowman's Valley 14 miles southwest of Gazelle. Most of the specimens came from the SE ¼ sec. 29, T.41N., R.7W., M.D.M. The fauna includes: a new species of *Halysites, Favosites limitaris, Favosites helderbergiae?, Favosites favosa, Billingsaria? sp., Coenites sp., Syringopora hisingeri?, Heliolites interstinctus?, Hormotoma sp.*, and over 30 unidentified brachiopods, Bryozoa, and colonial corals.

Four specimens that resemble the Ordovician *Lophospira*, a fragment of *Hormotoma?* sp., several minute *Loxomena?* sp., and a large gastropod came from similar limestone outcrops in Section 20.

The northeast-southwest valley developed either on a fault or along the basal contact. The unfossiliferous cherts and slates that completely underlay the northwestern slope are rarely present southeast of the valley.

Seismological Society of America

GEOMORPHIC RECORD OF EARTHQUAKES IN WESTERN UNITED STATES

ELIOT BLACKWELDER
Stanford University, Calif.

Scarplets and other topographic features due to fault dislocations are widely distributed in both space and time. Some are historic, others Recent, and still others are of late Pleistocene age. Those now known to the writer are listed, and some of them described.

These topographic effects seem to be best preserved in rather dry regions, not so well in extreme deserts, and least of all in moist regions.

The severity of the individual earthquakes is roughly indicated by the relief of such scarplets, insofar as they are the results of single rather than successive movements along the faults.

PERIODS OF SEISMIC WAVES

PERRY BYERLY
University of California, Berkeley 4, Calif.

This is a final report on the periods of waves measured on the records of near earthquakes recorded on Wood Andersen seismographs at the stations of the University of California network. This work was commenced under a grant from the Penrose Bequest. The number of periods read was 18,636. The data do not suggest that certain periods are preferred at any station (*i.e.*, that the localities of the stations have free or resonance periods). The coda periods are longer for the more distant shocks. There is some tendency for P and S periods to be greater for more distant shocks. The periods increase with the Richter magnitude of the shocks. For the data available the epicentral distance is usually greater for the shocks of greater magnitude.

INFLUENCE OF RESERVOIR LOADING ON LOCAL EARTHQUAKE ACTIVITY

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U. S. Coast and Geodetic Survey, Washington, D. C.

Seismographs have been in operation for several years near the reservoirs impounded by the three large Bureau of Reclamation dams—Boulder, Grand Coulee, and Shasta.

It was found, from the study of the seismograph data, that the added weight of the impounded water may cause small earthquakes if conditions are right. The area in question must be already faulted, and the added load must be heavy and concentrated over a small area. Severe earthquakes cannot be caused by reservoir loading in itself. If the area has not been faulted, new faults will not form because of the reservoir. Readjustment of the crust to the added load will be flexural, and small earthquakes will not occur in consequential quantity. This paper is a continuation of an earlier report on the Boulder Dam area and includes also the results obtained from seismological studies near Shasta and Grand Coulee dams.

DISCONTINUITIES BETWEEN LAYERS IN THE INTERIOR OF THE EARTH

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United Geophysical Co., Pasadena, Calif.

If two isotropic separately homogeneous solids are in contact and the stress on one side of the interface is hydrostatic, then the stress is not hydrostatic on the other side unless very special relationships hold between the elastic constants. Thus a stress difference of zero may suddenly become large as one crosses the interface. The more general case in which the stress is not hydrostatic on either side of the interface is discussed in some detail. It is shown that the Poisson solids occupy a curiously singular position with respect to interface behavior. The effect of interfacial friction is briefly discussed.

The above problem may be given a more general formulation in terms of thermodynamic relations. In fact, this appears to be the proper setting for this problem which in some cases may be associated with the problem of the origin of deep-focus earthquakes and possibly also with the problem of cone-in-cone fracturing.

May there not be a limit beyond which pressure may not be increased without forming a fluid of any solid simply owing to the fact that no solid can be considered as perfectly homogeneous as we examine it in greater and greater microscopic detail? Under excessively high pressures stress differences may become so high that continual microscopic adjustments are occurring to such an extent that the resistance to any shear stress superimposed upon the material is impossible. Is this the mechanism of the "fluid" core of the earth?

EFFECT ON SEISMIC WAVES OF PASSING THROUGH A FOCUS

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We consider first the effects where, prior to passing through the focus, the wave front is cylindrical. In such a case a delay occurs amounting to a quarter wave length shift of phase in passing through the focal line. For the case of a spherical wave front coverging on a point focus the delay is half a wave length. In the case of a generally curved wave front the delay is a quarter of a wave length on crossing each focal line.

The above considerations are developed for the steady state case but may, by a Fourier integral analysis, be applied to almost any pulse that may occur.

Another important consideration is the fact that the curvature of the wave-front surface is a "point property" which usually varies from point to point on the surface and so the above delay effects apply to the waves from only a small part of the wave front—the actually observed result must be an integrated result covering the whole wave front.

The above effects are deduced on the assumption that the equation of motion is the strictly linear wave equation. One may perhaps have reservations regarding the validity of this equation at a focus where nonlinear effects may possibly enter. Even in the case where nonlinear effects enter one may perhaps be justified in assuming that the "linear part" will behave as here described.

Effects described above have been known for many years in optics.

SEISMIC RAYS AND WAVES

C. Y. FU

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The equations of motion of an elastico-viscous solid in which the elastic constants vary with position are deduced. These can be reduced to the form of the wave equation only when the gradients of the elastic constants are small. By the method of Sommerfeld and Runge, these equations are compared with the equation of the characteristic function whence the condition for the validity of the ray method is obtained. It is similar to De Broglie's criterion in wave mechanics. Expressed in terms of measurable quantities in seismology, the condition is applied to the data recently obtained by Gutenberg for the upper layers of the earth's crust. The equations of the rays are then obtained for several particular functions of the wave function from the equation of the characteristic function, following a method originally used by Epstein.

RAPID TECTONIC ELEVATION CHANGES IN SOUTHERN CALIFORNIA

U. S. GRANT AND JAMES GILLULY

University of California, Los Angeles 24, California

Repeated precise leveling by the U. S. Coast and Geodetic Survey in southern California demonstrates that an elongated uplifted dome was formed 2½ miles east of Signal Hill in Los Angeles County between level surveys of 1931–1932 and 1933–1934. The interval between these surveys embraced the Long Beach earthquake of March 10, 1933. The maximum known uplift on this dome was 0.60 foot at Bench Mark H 51, at the intersection of Palo Verde Avenue and Stearns Street. Isobases drawn from scattered bench marks show that the elevation decreased to zero change about 8 miles northwesterly (along the axis of the elongate dome) and about 3 miles northeasterly down its flank. This domal uplift formed on a low plain, and the axis of the uplift roughly parallels the Newport-Inglewood fault zone.

Along the Santa Fe Railway from San Bernardino to Victorville, precise level surveys in 1906, 1924, and 1943–1944 demonstrate a progressive uplift that increases from San Bernardino northward to a maximum just east of the San Andreas fault trace in Cajon Pass, from which it gradually decreases to a relatively stable bench mark at Victorville. The maximum uplift in the 37-year period amounts to 0.4114 meter (1.362 feet) at B.M. K2.

The uplift east of Signal Hill occurred within a brief interval; the uplift in the Cajon Pass appears to be a slow, enduring movement. Both appear to be removed from artificial influences and are accordingly considered tectonic.

ENERGY RELEASE IN EARTHQUAKES

B. GUTENBERG AND C. F. RICHTER

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Energy values given here may require later multiplication by a correction factor. This will not affect their ratios. The mean annual release of seismic energy radiated in elastic waves is 12×10^{24} ergs (85 per cent in shallow earthquakes, 12 in intermediate, 3 in deep shocks). Individual years 1904–1946 range from 60×10^{24} ergs in 1906 to 2×10^{24} in 1930. The highest seismicity occurs from Japan to the Solomon Islands. In the Marianas Islands, the Hindu Kush, and Rumania, more energy is released in intermediate than in shallow shocks. The annual average for the world includes about 2 great shallow shocks and 17 other major earthquakes, of which about 5 are intermediate and 1 is deep. Four independent series of large shocks (northern and southern, shallow and deep) indicate an annual period with maxima in the second half of the calendar year. Similarly, shallow as well as deep shocks show a maximum at about 6 hours of the local day. Significance tests for the individual series are not favorable.

CENTRAL CALIFORNIA EARTHQUAKES 1818–1829

GEORGE D. LOUDERBACK

Univ. of Calif., Berkeley 4, California

The author discusses various conflicting and poorly documented or undocumented published statements and their relation to the Mission records.

DOMINGUEZ HILLS, CALIFORNIA, EARTHQUAKE OF JUNE 18, 1944

SAMUEL T. MARTNER

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Two small earthquakes, which originated at 4:03:33 p.m. and 7:06:06 p.m. P.S.T., June 18, 1944, were felt generally in the Los Angeles metropolitan area and did slight damage in the region

of Compton and Gardena, California. Damage included the collapse of 16 wells in the Rosecrans Oil Field. Epicenters of these shocks have been determined to be in the locality of 33° 51′ N. Lat. and 118° 15′ W. Long. This occurrence is compared with a previous happening, and the parallelism between the two cases is so striking that it is concluded that the mechanism in both cases was similar.

PERIOD INCREASE OF SEISMIC SURFACE WAVES

WALTER H. MUNK

Scripps Institution, La Jolla, Calif.

A theory for the period increase of seismic surface waves is derived from very general assumptions. The derivation follows entirely from the *kinematics* of wave motion. Good agreement between computed and observed values indicates that the period increase is a phenomenon inherent in the kinematics of wave motion and is not related to the viscous properties of the transmitting medium. These conclusions apply also to the observed period increase of tsunamis and of swell (Munk, 1947), which obey the general theory.

The theory leads to two expressions which are especially suitable for comparison with observations. A differential form $dT/dx = (1/V) - (1/C) - \partial T/\partial t$, gives the period increase with distance of an *individual* wave of group velocity V, wave velocity C, and rate of period decrease at a fixed point, $\partial T/\partial t$. At integrated form $T = f(t - x/V)$ requires that from a single disturbance all waves at any time t and distance x must obey the same functional relationship. Assuming V as a function of T according to some observations compiled by Gutenberg and Richter, the first expression leads to a period increase of the order of 1 second per 1000 km, in agreement with empirical evidence. The second expression is applied to records of a small Mexican earthquake in 1943 and gives at least the right order of magnitude.

PRESENT STATUS OF ENGINEERING SEISMOLOGY

FRANK NEUMANN

U. S. Coast and Geodetic Survey, Washington, D. C.

Instrumental data obtained in recent years on destructive earthquake motions show wide variations from the hypothetical figures used by engineers in designing structures to withstand earthquakes. Early efforts to use the new data in predicting building stresses were largely stymied by the formidable mathematical problem involved, but the development of the torsion pendulum analyzer broke this bottleneck. The analyzer mechanically determines the maximum stress in terms of an equivalent static acceleration regardless of the complexity of the ground motion. But the torsion pendulum in its simplest form assumes absence of damping in the structure and rigid coupling with the ground so that actual conditions are seldom simulated and computed stresses are sometimes excessively high. Efforts are being made to study in more detail the influence of damping and foundation factors. Other lines of attack are open, but this is the theoretically correct one and should be followed through. Additional field data will probably be needed, and a more concentrated effort must be made in the analytical and laboratory phases of the problem before a satisfactory solution is reached.

MEASUREMENT OF PERMANENT GROUND DISPLACEMENT BY GEODETIC AND SEISMOGRAPHIC METHODS

FRANK NEUMANN

U. S. Coast and Geodetic Survey, Washington, D. C.

During the Imperial Valley earthquake of May 18, 1940, an accelerograph record was obtained at El Centro, and subsequently a geodetic resurvey of the area revealed a permanent displacement of the marker at El Centro. The paper is primarily a discussion of the accelerogram analysis published in 1941 in the light of the geodetic results now available. It is concluded that with adequate instrumentation it will be possible to compute permanent displacements of this character.

SEISMOLOGY IN MONTANA

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Geologists find ample evidence for the occurrence of earthquakes throughout the mountainous portions of Montana in the geological past, while the first definite report of a quake in the State seems to have been in 1869. Most quakes seem to have occurred in the southwest, between Helena and Virginia City, but a new epicentral region appears to be developing around Kalispell in the northwest. The destructive quakes in Helena in 1935 have been followed by many other nondestructive quakes numbering in the thousands up to the present time. Strong-motion type instruments are in operation in Butte, Bozeman, Helena, and Great Falls. Also, a Wood-Anderson sensitive-type instrument is in operation in Butte. The question of installing an instrument at Kalispell is being studied. Earthquake questionnaire cards are sent out from Butte and are studied co-operatively with the San Francisco Office of the Seismological Field Survey. Isoseismal maps have been constructed. When an important shock occurs, a member of the Montana State Bureau of Mines is sent to the scene and makes a report to the Collaborator, who transmits it to San Francisco. The Weather Bureau Office in Helena keeps a record of Montana quakes. The Collaborator is seeking to improve coverage by questionnaire cards. In general, interest in seismology is becoming increasingly pronounced in Montana. Newspapers give prominence to earthquake reports.

SEISMOLOGY IN NEW MEXICO

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About 99 per cent of New Mexico's 575 earthquakes have originated in a narrow much-faulted belt located in the Mexican Highland section of the Basin-Range province adjoining the southeastern border of the Colorado Plateau. Shocks have been concentrated: (1) northwest of Silver City, (2) Socorro, (3) Belen, and (4) Albuquerque. The three last-named localities lie in a 75-mile strip along the Rio Grande Depression; here shocks have been recorded in 25 different years between 1855 and 1947, chiefly near Socorro and Belen. New Mexico earthquakes tend to occur in swarms and exhibit nocturnal and July-December maxima; there have been a number of moderately strong shocks, resulting in occasional property damage but no loss of life, and several shocks have affected fairly large areas (75,000 to 180,000 square miles).

There is no seismological station in New Mexico, and thus practically all available information is noninstrumental. Since 1940, questionnaire cards have been distributed among such groups as University students and alumni, at teachers' conventions, and to insurance agents, oil company agents, personnel of the U. S. Forest Service.

In the event of a major shock, a number of geologists and engineers would be available for necessary investigations.

Considerable progress has been made during the last decade and especially the last 3 years in the detailed mapping of hundreds of faults along the Rio Grande belt.

STATUS OF SEISMOLOGY IN OREGON

E. L. PACKARD

Oregon State College, Corvallis, Oregon

Earthquakes felt and recorded in Oregon have been few in number and of low intensity. Until recently the record has been based largely upon press accounts. Only 55 such records were reported previous to 1932. The proportion of those originating in Oregon is presumed to be very low.

Such an apparent paucity of local earthquakes is surprising in view of the large faults in parts of Oregon; the intensive volcanic action during the Tertiary and Quaternary; and the nearness to recognized seismic regions.

A better understanding of this condition will be obtained from the Wood-Anderson seismograph recently installed by Dr. H. R. Vinyard at Oregon State College, especially when supplemented by additional equipment.

TRANSMISSION OF EXPLOSIVE IMPULSES IN THE SEA*

R. W. RAITT AND T. F. JOHNSTON

Marine Physical Laboratory, San Diego, Calif.; Naval Ordnance Laboratory, Washington, D. C.

Under-water explosions produce short, intense, steep-fronted pressure pulses that have proved useful in the study of under-water transmission. Observations made at sea near San Diego by the UCDWR, using electric blasting caps as sound sources, demonstrate a number of significant features of sound transmission in the sea.

During the measurements, the sea temperature near the surface generally decreased with depth, causing downward refraction of the sound rays. A theoretical "shadow zone" is cast by the sea's surface under these conditions.

Oscillograms of the received pulses fall into three general classes.

(1) Near the source the time difference between the direct and surface-reflected pulse permits their resolution. In this region the direct-pulse shape is usually independent of distance from the source, and its intensity can be calculated from ray theory with reasonable accuracy.

(2) As the boundary of the "shadow zone" is approached, the initial time of rise of the pressure pulse increases sharply with range, the intensity decreases, and the direct and reflected pulses are no longer resolved.

(3) Within the "shadow zone" the sound is weak and decreases rapidly with increasing range. The pulse becomes elongated and executes several oscillations with a period of the order of a few hundred microseconds.

PROJECTED ACTIVITIES, U. S. COAST AND GEODETIC SURVEY, IN SEISMOLOGY

ELLIOTT B. ROBERTS

U. S. Coast and Geodetic Survey, Washington, D. C.

This paper treats of the instrumental and operational plans of the Bureau for better service to the public. Emphasis will be upon the engineering seismology or "strong-motion" studies in western United States, and upon the problem of a seismic sea wave warning service for the Pacific Ocean area.

RECENT EARTHQUAKES IN LASSEN VOLCANIC NATIONAL PARK

HARRY B. ROBINSON

Mineral, California

A swarm of earthquakes, many of which were felt locally, were recorded by the Mineral seismograph from April 29 to May 5, 1946. The swarms started again early in June and continued into August. The sharpest quake was of such intensity that campers in the park, thinking Lassen Peak was erupting, left the area during the night.

Based on existing faults, renewed hot-spring activity, local reports on felt quakes, and S-P intervals measured on seismograph records from Shasta Dam and Mineral, the source of these shocks appears to be in the Warner Valley section of Lassen Volcanic National Park.

* This article is based upon work performed for the Bureau of Ships and OSRD under Contract NObs-2074 (formerly OEMsr-30) with the University of California Division of War Research.

PROGRESS REPORT OF SEISMOLOGICAL WORK BY THE UNITED STATES COAST AND GEODETIC SURVEY IN 1946

FRANKLIN P. ULRICH

U. S. Coast and Geodetic Survey, Old Mint Bldg., 5th & Mission Sts., San Francisco, Calif.

This paper is the annual progress report of the United States Coast and Geodetic Survey on collecting information on felt earthquakes in the Western United States; the strong-motion seismological program; the vibration program; the co-operation with other organizations in instrumental upkeep or maintenance, and the co-operative seismological program in the American Republics.

CO-OPERATIVE SEISMOLOGICAL PROGRAM IN UTAH

J. STEWART WILLIAMS

Utah State Agricultural College, Logan, Utah

In the last 5 years approximately 1000 persons have been furnished franked questionnaire cards and have been asked to serve as earthquake observers. They include alumni of U.S.A.C., high-school science teachers, employees of public-utility companies, and others. This observer system, together with the good news coverage provided by the State's newspapers, is believed adequate to insure the collection of the essential data of all earthquakes. The yield of cards for particular earthquakes has, however, been disappointingly low, probably because of the relative infrequency of earthquakes in Utah.

Improvement appears to lie in increasing the general public interest in seismological work and in sustaining the interest of the observers by keeping them informed of the results of the program. An attempt will be made to give wide publicity to (1) stories of recent advances in seismology, and (2) the earthquake history of Utah. A complete catalogue of Utah's earthquakes, including an intensity estimate and a tentative assignment to the known faults of the area, is being prepared.

SEISMOLOGY IN ARIZONA

ELDRED D. WILSON

Arizona Bureau of Mines, Tucson, Arizona

Reports of earthquakes sufficiently strong to impress the general public have been comparatively rare during historic time in Arizona. Some unrecorded shocks may have occurred during the past century, when the population was very sparse.

None of the known tremors resulted in appreciable damage to persons or property.

Numerous minor quakes in northwestern Arizona have been recorded during the past 15 years.

Much crustal disturbance has occurred in Arizona throughout geologic time, and the last major deformation affected Pliocene rocks.

A reconnaissance geologic map of Arizona was published in 1924. Detailed studies have been made in many areas, principally mining districts. Much remains to be done, however, before the structure of the State as a whole can be adequately interpreted.

There is a U. S. Magnetic observatory at Tucson. The Coast and Geodetic Survey Collaborator sends questionnaires to University alumni and other people throughout Arizona. Owing to increased industrialization, hydro-electric and irrigation projects, as well as a larger population, the importance of seismology is apparent to them.

ABSTRACTS OF PAPERS PRESENTED AT SECTION E MEETING IN CHICAGO, DECEMBER 26–27, 1947

SOME METHODS OF TRACING SOURCES OF WELL CONTAMINATION IN MISSOURI

KEITH E. ANDERSON

Missouri Geological Survey and Water Resources, Rolla, Missouri

Deep wells are the principal source of water for municipal and industrial purposes in southern Missouri. Dolomites make up a large part of the rocks near the surface in this area; and the presence of joints, solution openings, caverns, and sink holes in these dolomites may cause deep wells to become contaminated by surface water or shallow ground water unless proper precautions are taken at the time of drilling.

Methods employed successfully to trace possible sources of contamination include the use of salt and organic dyes, the correlation of water-level fluctuations in the well with rainfall, and the observation of water levels in test borings near a contaminated well.

In several instances of contamination, salt has been introduced into near-by abandoned wells and into sink holes, and the resulting increase in chloride content of the water pumped from the contaminated well has been determined by chemical analysis. Organic dyes have been used similarly.

In one instance of contamination of a deep well, a hydrograph of daily static water-level measurements in the well showed very close correlation with local rainfall records and almost no correlation with pumpage. This indicated the rapid entry of rainfall into the ground through sink holes in the area.

In another instance of contamination, a connection between the imperfect casing seal of a deep well and a near-by pool of impounded surface water and sewage was established by boring test holes and observing the water level in the test holes when the well was pumping.

THE MISSISSIPPIAN FLORA

CHESTER A. ARNOLD

University of Michigan, Ann Arbor, Mich.

The Mississippian flora is one of the least investigated fossil floras of North America. David White recognized two phases—a lower or Pocono phase, and an upper or Chester phase. The Pocono flora is characterized by *Triphyllopteris* and lycopods of the *Lepidodendropsis* type. The Chester flora is set off by the occurrence of *Cardiopteris polymorpha*, lycopods resembling the Old World *Lepidodendron volkmannianum*, and *Asterocalamites*. Both of these floras are distinct from the late Devonian below and the early Pennsylvanian assemblages above. The Wedington sandstone member of the Fayetteville shale contains the only Mississippian land flora yet described from the Mid-continent region. The plants support the middle or early late Chester age indicated by the invertebrates. The flora of about 40 species in the upper New Albany shale, and described as Devonian, contains as many or more Mississippian than Devonian elements. Practically all of the species found there, however, are restricted to this series and consequently are of limited value in determining the age of the plant beds.

GROUND-WATER EXPLORATION BY ELECTRICAL RESISTIVITY METHODS*

CARL A. BAYS AND MERLYN B. BUHLE

Illinois State Geological Survey, Urbana, Illinois

The electrical-resistivity method is used primarily for the location of shallow water-bearing sand and gravel deposits in glacial drift and alluvium. The method delineates these deposits and provides the basic information for the economic location of test holes.

Portable instrumentation using modified Gish-Rooney equipment with Wenner electrode con-

* Published with permission of the Chief, Illinois State Geological Survey.

figuration has proven the most useful method of field operation. Rapid and inexpensive surveying of areas of potential water-producing terrain is possible.

Interpretation of the indirect electrical data is based on the available knowledge of the geologic conditions in any subject area and the use of a number of empirical graphic methods of analysis.

ELEMENTS IN METEORITES AND THE EARTH'S ORIGIN

HARRISON BROWN

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An attempt has been made to study the composition of meteorites from a more quantitative point of view than has been attempted heretofore. Investigations have been made of experimental and theoretical approaches that might lead to more rigid comparisons between terrestrial and meteoritic matter. Particular stress has been placed upon the following studies: (1) a statistical study of the gross composition of meteorites; (2) the distribution of elements between meteoritic phases; (3) average composition as a function of metal phase content; (4) correlation between element distribution, thermochemical data, and general thermodynamic considerations.

It is demonstrated that if one is to assume that the observed distributions of elements represent equilibrium distributions, then equilibrium must have been established at temperatures of the order of 3000° C. and pressures of the order of 10^5–10^6 atmospheres. Similarly, the conditions at which equilibrium was achieved varied from meteorite to meteorite in such a way that the greater the metal phase content, the greater the temperature and/or the pressure. The data indicate strongly that meteorites had their origin in a planet, similar to the earth in general physico-chemical characteristics.

The correlated data, together with the observed metal-phase frequency curve and *a priori* considerations of compressibility, are utilized to correlate the observed densities of Mars and the Earth-Moon combination. It is concluded that the compositions of the two planets are strikingly similar and that the physico-chemical processes that entered into the formation of each were the same.

STATUS OF MISSISSIPPIAN STRATIGRAPHY IN THE APPALACHIAN REGION

BYRON N. COOPER

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Critical study of published information on the Mississippian system of the Appalachian region reveals a long and continuing neglect of one of the thickest and most varied developments of the Mississippian in North America.

Abundant faunas and floras in the Appalachian Mississippian have received surprisingly little systematic study and description. These assemblages offer exceptional opportunities for paleobiological and biostratigraphical study. Only a beginning has been made toward understanding the local and regional relationships of numerous facies. In many sections of the Appalachian region the determination of the position, stratigraphic character, and geologic significance of both systemic boundaries necessarily awaits detailed study. A large number of correlations and formation identifications, now current, are not only valueless but deceiving, because they are based upon inadequate paleontology or, in some instances, upon no paleontology. The widespread persistence of certain lithologic divisions has been mistaken for evidence of contemporaneous deposition, with lamentable results.

The keynote of this summary is a strong and urgent plea for renewed interest in Appalachian stratigraphy and for an early beginning to the systematic study of Mississippian fossils.

KINDERHOOK MICROPALEONTOLOGY

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Both published and unpublished information on Kinderhook microfaunas, together with significant macrofaunas and floras, are considered in an effort to evaluate these microfaunas, particularly the conodonts, for useful stratigraphic purposes. Of all classes of fossils represented, the conodonts are best known, because of the relatively large number of papers published on them. The ostracodes,

which occur in several zones, are little known. Other kinds of microfossils, such as Foraminifera, holothurian, and echinoid fragments, spores, ?radiolarians, and nepionic forms of many of the common larger fossils are the subject of few reports or have been neglected entirely

GROUND-WATER HYDRAULICS AS A GEOPHYSICAL AID

JOHN G. FERRIS, HYDRAULIC ENGINEER

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The recent development of mathematical tools for the solution of problems in ground-water hydraulics has made it evident that, under certain conditions, it is possible to interpret and infer the geologic structure of finite aquifers, from a study of their hydraulic behavior. The primary qualifying condition requires that the aquifer be bounded by relatively impermeable material. Typical examples of this structure include the out-of-phase displacement of consolidated strata of variable permeability, by faulting, and the bounding of highly permeable valley fills by low permeability walls.

It is shown that the Method of Images, which is time-honored in its application to problems in the conduction of heat or electricity, is applicable to the solution of similar problems in the flow of ground water, in aquifers of finite areal extent. Although this method requires considerable simplification of the field conditions to permit its use, nevertheless the results obtained are of inestimable value in the prediction of aquifer performance and in the interpretation of the probable geologic structure.

Observational data are presented, and an analysis is made to indicate the differences between a geologic cross section of a drift-filled channel, as determined by test drilling, and the idealized cross section, as determined by the hydraulic evidence. The possibilities of this method as a geophysical aid in locating several types of geologic boundaries are outlined with appropriate references to the limitations of the method.

METHODS USED IN GROUND-WATER INVESTIGATIONS IN KANSAS

V. C. FISHEL

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Co-operative investigations of the ground-water resources of Kansas were started in 1937 by the Federal Geological Survey, the State Geological Survey of Kansas, the Division of Water Resources of the Kansas State Board of Agriculture, the Division of Sanitation of the Kansas State Board of Health, and the City of Wichita. These investigations are generally made on a county unit basis, but other special investigations have been made. Twenty-two reports prepared as a result of these investigations have been published by the State Geological Survey of Kansas, and several other reports are awaiting publication or are nearly completed.

The ground-water investigations in Kansas include the mapping of the geologic formations that have a direct bearing on the ground-water resources and a study of the occurrence and utilization of ground water. Records of stock, domestic, irrigation, municipal, and other wells are collected, and the data are used for preparing water-table contour maps and depth-to-water maps. If possible, pumping tests are made to determine the yields of typical wells and the permeability of the water-bearing materials. A state-owned test-drilling machine is used for test drilling to determine the character and thickness of the water-bearing materials. From 20 to 60 test holes are drilled in each county. Also, about 30 samples of water are collected from typical wells in each county for chemical analyses.

A systematic observation-well program is an essential part of our work. During 1946, water-level measurements were made periodically in 480 wells in 47 counties in Kansas.

DEVELOPMENT OF GROUND WATER FOR MILITARY USE IN MOROCCO AND ITALY 1942-1945

FRANK C. FOLEY

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The United States Army in Morocco and Italy was supplied with adequate modern equipment for development of ground water. Personnel trained for locating sources was available but was not always utilized to best advantage. The speed necessary under theater of operations conditions frequently precluded desirable investigation. Intelligence reports in some areas, particularly Sicily, were excellent and detailed, in others generally accurate but not in adequate detail. Considerable information was obtained from civilian sources. In the Naples and Rome areas about 50 wells were drilled, the majority of them successful. The volcanic rocks proved to be good aquifers. Wells drilled in the Phlegraean Fields yielded good quality cold water in some instances and warm, mineralized water in others. In the Leghorn area 53 wells were drilled of which 31 were successful, particularly in the delta of the Arno River. Drive points were used in a few places. Wells outside the area of the delta were almost all unsuccessful. Most water supply in combat areas was obtained from existing well, spring, or surface-water sources.

METHODS USED IN GROUND-WATER INVESTIGATIONS IN IOWA

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In Iowa, ground water is developed from wells ranging in depth from a few feet to 3435 feet, utilizing as sources of supply rocks of 20 formations and 8 series from Pleistocene to basal Cambrian. Some units contain numerous aquifers. Folding and faulting is sufficient to affect ground-water distribution and quality. Geology, therefore, plays an unusually important role in the ground-water investigations.

The work, done co-operatively by the State and Federal Geological Surveys, embraces state-wide and local studies of surface and subsurface geology, well production, static and pumping levels, water temperatures, mineral content, well construction, and underground movement of water laterally and vertically.

Many of the basic data can be shown on maps. Map types include: subareal, subsurface contour, isopach, piezometric, and mineralogical quality. They are continually revised as new information is received.

Well cuttings and well-construction data are collected through the co-operation of well drillers and engineers. After preparation the cuttings are examined microscopically; results are plotted in color on strip logs, correlated, and generalized descriptive logs are prepared.

Pumping tests are conducted on selected wells to obtain water levels, productions, temperatures, and water samples for chemical analyses. Permeability data are obtained where possible and desirable.

A shallow-well water-level program has been carried on for 10 years. Records are obtained by using recorders or manual measurements.

Resistivity and electrical well logging have been experimentally tried and will be useful when funds are available for adding these supplementary facilities on a permanent basis.

SUBSURFACE STUDIES OF PLEISTOCENE AQUIFERS ALONG THE ANCIENT MISSISSIPPI VALLEY IN CENTRAL ILLINOIS*

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Studies of Pleistocene aquifers along the Ancient Mississippi (present middle and lower Illinois) valley in central Illinois included: (1) construction of a bedrock-surface map of the ancient valley and adjoining uplands; and (2) description and correlation of Pleistocene deposits revealed by sample well cuttings, surface exposures, and drillers' records. The bedrock-surface map is based mainly on well data, but additional evidence is provided by locations and elevations of bedrock exposures, present drainage relations, and the glacial geology of the region. The Pleistocene deposits are differentiated largely on the basis of buried soils and weathered zones, physical properties, and stratigraphic sequence.

The major Pleistocene aquifer of the region is the Sankoty sand which supplies most of the ground water in the Peoria industrial area. It occurs as an extensive basal fill along the bedrock valley and is probably continuous along most of the larger valleys of the Ancient Mississippi system. The sand

* Published with permission of the Chief, Illinois State Geological Survey

underlies Kansan, and possibly Nebraskan, drift and is considered early Nebraskan. Less important aquifers are present in the Kansan, Illinoian, and Wisconsin drift sheets which overlie the Sankoty sand.

USE OF SOIL MAPS IN GROUND-WATER INVESTIGATIONS IN INDIANA

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A detailed investigation of the ground-water resources of Indiana by the U. S. Geological Survey and the Indiana Department of Conservation has been in progress for several years. An integral part of this work is the detailed mapping of the bedrock and surficial geology of certain areas. In any quantitative ground-water investigation, the types of rocks in which ground water may be stored, their extent and thicknesses, their areas of outcrop, and the presence of impermeable rocks that confine aquifers or hinder recharge to the aquifer must be known. Recent classification by the Engineering and Agricultural Experiment Stations of Purdue University of the pedological soil series of Indiana on the basis of parent materials, depth of leaching, and topographic position facilitates the mapping of surficial geology from maps of the soil surveys of the U. S. Department of Agriculture, especially the more recent surveys based on aerial photographs. Preliminary maps of surficial geology based on the soil-survey maps are checked by field reconnaissance and are correlated with subsurface information obtained from existing wells, test drilling, and geophysical methods. The preparation of a map of the glacial geology of Noble County from an unpublished soil map prepared by Purdue University is discussed, showing the correlation of soils to glacial geology.

MISSISSIPPIAN OSAGE-MERAMEC BOUNDARY

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Outstanding evidence indicating a major break between Osage and Meramec rocks has been accumulated. A sharp unconformity and reworked Osage materials in basal Meramec rocks characterize the contact in the upper Mississippi Valley. A karst topography was developed on the late Osage surface prior to the deposition of Meramec rocks in the Batesville, Arkansas, region. The entire Osage section is remarkably truncated and overlapped by rocks of Moorefield age in the northeastern Oklahoma Ozarks. The contact between the Cowley formation of Meramec age and the underlying Osage surface is equally unconformable in the subsurface of Kansas. Rocks of Meramec age overlap northward onto rocks of Osage age with marked unconformity in southwestern New Mexico. Rocks carrying a *Lithostrotion* fauna were deposited on a highly developed solution surface developed on Kinderhook rocks in northern Montana. The Rundle limestone rests with marked unconformity on Kinderhook rocks in southern British Columbia. In the Wapiti lake area just south of the Peace River, Meramec rocks transgressively overlap against a markedly eroded Kinderhook surface. In Yukon and Alaska rocks of Meramec age overlap widely onto Devonian and older rocks.

Osage rocks in general lie in areas immediately underlain by Kinderhook rocks. Meramec rocks are much more widespread than Osage rocks and appear to be much more closely associated with rocks of Chester age than with the underlying Osage rocks.

The paleontologic break at the top of the Osage is spectacular. Very complete brachiopod and crinoid evolutionary series can be traced through Kinderhook and Osage rocks. Almost without exception they come to abrupt endings at the end of the Osage. Meramec species on the other hand show close relationships to Chester and Pennsylvanian species.

PAST THEORIES FOR THE ORIGIN OF THE EARTH

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The two theories which are historically the most important: the Nebular Hypothesis of Laplace, and the Planetesimal Theory of Chamberlin and Moulton with the subsequent changes by Jeans into the Tidal Theory and by Jeffreys into the Collision Theory. The principal features of each are summarized, and the most important objections which in each case have proved to be fatal to the theory. (Philosophical implications of cosmogony: viewing the origin of the earth as an almost inevitable result or evolution of a typical star leads to the acceptance of the plurality of worlds, but viewing it as the consequence of a cataclysm in itself fairly improbable of occurrence leads to the acceptance of the earth as an almost unique object.) Some of the newer theories on the subject are mentioned, and the writer enumerates the salient facts and characteristics of the solar system which must form the basis of any new theory.

GEOLOGICAL APPROACH TO THE PROBLEM OF EARTH ORIGIN

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The "vestiges of creation" from which we attempt to deduce a satisfactory hypothesis of earth origin cannot be sorted into sharply defined categories—one for astronomy, another for geology, and so on. In general, the astronomer is interested in the earth as a member of the stellar galaxy, whereas the geologist is interested in the earth as the abode of man. There is obviously a considerable area of overlap. Nevertheless, there is a distinctively geological approach to the problem, and geologists must give it careful consideration. The thorough-going analysis of the origin of ore deposits, of the nature of diastrophic forces, of the processes of vulcanism, of the causes of glaciation (including those of pre-Cambrian time) leads one to the investigation of the juvenile history of the earth.

Perhaps the astronomer should have the task of describing the birth of the earth, but no one can expect him to accomplish that task unless the geologist can give the specifications of a new-born planet that would necessarily evolve into an earth as it is today. The geologist must therefore probe the depths of the earth to construct an earth-model and project back an inferential history of a juvenile earth.

Was the juvenile history of the earth essentially an expression of progressive condensation from an initial mass of solar gas, through a partially liquid phase to a partially solid body? Or did this history include significant growth through accretion of essentially solid meteoritic (planetesimal) fragments? Influenced strongly by the research of T. C. Chamberlin, Jeffreys, Daly, and others, geological opinion has oscillated between affirmative answers to each of these fundamental questions.

The stratiform structure of the earth's interior, with the discontinuities between successive "spheres," made known by seismologists, inclines the geologist toward an affirmative answer to the first question. The geographic segregation of diverse materials in the lithosphere inclines the geologist toward an affirmative answer to the second. The attempt to discover an adequate cause of the earth movements responsible for the Tertiary mountain systems has had noteworthy repercussions in geological thought along these lines, but each chain of hypotheses has many weak links.

Recent information concerning the physical properties of matter under great pressure and at high temperature has opened up new possibilities for gravitational segregation within the body of a solid earth and leads to a possible compromise between the divergent trends of thought. However, at the moment the geologist cannot be of as much help to the astronomer seeking an explanation of the birth of the earth as he would like to be.

AMERICAN MISSISSIPPIAN AMMONOID ZONES

A. K. MILLER

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No comprehensive study of our Carboniferous ammonoids has been attempted since the very beginning of the present century. Only three ammonoid zones can now be recognized in the American Mississippian system. These seem to be more or less equivalent to our Kinderhook, Osage, and Meramec-Chester beds, and they are characterized by the genera *Protocanites*, *Beyrichoceras*, and *Goniatites*, respectively. Locally, ammonoids are abundant in the Kinderhook and the Meramec, but elsewhere they are rare.

Our Devonian and Mississippian systems are not known to carry a single ammonoid genus in common, and only two stocks cross the border between them. One of these, the prolecanitids, became quite varied in the Mississippian, and they have a considerable amount of stratigraphic value there. The other stock that continues into the Mississippian is represented by the genus *Imitoceras*. Its descendants underwent a great development during the Carboniferous and gave rise to most of the many diverse forms known from there. Although Kinderhook ammonoids differ materially from those of the Devonian, they are close to those of the Osage. The latter, known from only a few specimens, are quite distinct from Meramec-Chester forms, which are more or less transitional with Early Pennsylvanian types.

PALEONTOLOGICAL COMPARISON OF AMERICAN AND EUROPEAN MISSISSIPPIAN SECTIONS

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A review of paleontological studies, primarily dealing with invertebrates found in Mississippian strata of North America and Europe, is summarized. The conclusion is reached that a two-fold division of rocks belonging to the system is most natural on both sides of the Atlantic. Kinderhookian and Osagian deposits, which are assigned to the Waverlyan (Lower Mississippian) Series, correspond closely to the Tournaisian rocks of Europe. The Meramecian and Chesterian stages of the American upper Mississippian, which comprise the Tennesseean Series, correspond to Visean and lower Namurian strata as defined in Europe.

SUBSURFACE EVIDENCE OF A LAND BRIDGE BETWEEN THE MID-CONTINENT AND NORTHERN ROCKY MOUNTAIN REGIONS IN MISSISSIPPIAN TIME

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Lithologic and paleontologic differences between Mississippian sediments of the Mid-Continent region and those of the Northern Rocky Mountain and Black Hills regions suggest that Mississippian seas were not continuous between these regions or that sea connections were greatly restricted. This paper presents available subsurface data in Nebraska and surrounding states in the light of this problem. The study is primarily lithologic.

Mississippian sediments are widely distributed in the subsurface of much of Iowa and Kansas, in southeastern and extreme southwestern Nebraska, and in southeastern Colorado. These sediments are lithologically similar to the Mid-Continent outcrops. Likewise Mississippian sediments occur widely in the subsurface of much of Wyoming, in western and northwestern South Dakota, in northwestern Colorado, and in extreme northwestern Nebraska. These sediments are lithologically similar to the Northern Rocky Mountain outcrops. However, Mississippian rocks appear to be absent in the subsurface in large areas between these two regions, and the Mississippian sediments of these two regions are lithologically dissimilar.

Mississippian sediments could have been deposited between these two regions and removed by post-Mississippian erosion, but this is not probable because of the apparent absence of good evidence suggesting facial changes. However, pre-Pennsylvanian rocks are deeply buried within much of the critical area, and the subsurface has not been thoroughly tested by drilling.

METHOD OF STUDYING INDUCED INFILTRATION FROM THE OHIO RIVER IN THE LOUISVILLE AREA, KENTUCKY

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The problem of evaluating the quality, quantity, and temperature of water which could be developed by induced infiltration from the Ohio River has been studied since 1944. This problem required development of general methods of approach as well as development of techniques for handling individual variables. The general problem involves questions of boundary conditions, types of flow in the aquifer, geologic conditions, interrelation of variables such as effects of barometric pressure and changes in river level on water levels, corrections for observation well screen loss and pumpage changes, and effects of temperature on well discharge and flow in the aquifer.

Data show that the existence of a hydraulic connection between the river and the aquifer can be established during a pumping test by studies of: (1) temperature, (2) chemical analyses, (3) water profiles, and (4) time drawdown relation at observation wells. Further, field data illustrate the merits of four methods of approach to the quantitative analysis of an infiltration pumping test in order to evaluate the effective distance to the line of infiltration and the transmission constant of the aquifer.

PROBLEM OF THE "MAYES" IN OKLAHOMA

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The Mayes formation consists of those beds of the Mississippian underlain by the Boone (Osagian) and overlain by the Fayetteville (Chesterian) in the outcrops in Mayes County, Oklahoma, and generally considered to be equivalent in age to Moorefield and Batesville. The name was recommended by L. C. Snider in 1915 and correlated as lower Chester. In 1927 George S. Buchanan applied the name to the dark argillaceous silty limestone of the Mississippian in the subsurface and correlated at least the lower part as being Meramecian. Ira H. Cram in 1930 introduced convincing evidence that the subsurface "Mayes" represented a facies change of the Boone and was therefore Osagian. Since that time the name has persisted, as has the confusion and controversy. Much new evidence has been revealed in deep drilling in western and northwestern Oklahoma. This evidence supports the general consensus of subsurface geologists that the "Mayes" of the subsurface is Osagian and is not a correlative of the Mayes formation of the outcrop section in northeastern Oklahoma.

PROBLEMS IN MISSISSIPPIAN STRATIGRAPHY OF THE SOUTHERN APPALACHIANS

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Mississippian studies of the Southern Appalachians (south of Kentucky and Virginia) needed for the solution of many stratigraphic problems fall into several categories, including: (1) refinement in stratigraphic subdivision; (2) establishment of lateral relationships from one place to another, especially between disconnected areas and areas of independent previous study; (3) correlation of the Southern Appalachian strata with the better-known units to the west and north; (4) establishment of the manner and time of origin of some of the units; and (5) establishment of the Mississippian-Pennsylvanian boundary.

An example of the need for (1) is seen in the case of the Bangor (restricted) limestone, a thick generalized unit of Chester age which should be subdivided and related to the known divisions of the Chester series of the Mississippi Valley. Examples of lack of (2) (probably originating separately) are the cases of (a) the Floyd shale of the Valley and Ridge Province in relation to the limestones of the Appalachian Plateau not far away, and (b) the Grainger shale in relation to units of the Chattanooga shale and younger rocks to the north and northeast. The manner and time of origin of the Chattanooga shale throughout its wide extent is still a controversy which leaves open the "black shale problem." The boundary between the Mississippian and Pennsylvanian is in considerable doubt at many places, even though some workers have claimed a disconformable contact. Field observations suggest transitional sedimentation across much of east Tennessee in addition to north-central and eastern Alabama.

Solution of many of the stratigraphic problems must await careful and detailed examination of the physical properties of the rocks and, particularly in several instances, a study of the fauna. Mention of many of the Mississippian stratigraphic problems of the Southern Appalachians is precluded within the limitations of this abstract.

PROBLEMS OF MISSISSIPPIAN STRATIGRAPHY IN SOUTHWESTERN UNITED STATES

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While in central Arizona the Lower Mississippian Escabrosa limestone is distinctly separable from the Devonian sequence of successive "cuboides," "hungerfordi," and "endlichi" faunal zones, in extreme southeastern Arizona and in southwestern Colorado the postulated and much-discussed Devonian-Mississippian gradation presents one of the current southwestern problems. Further problems are indicated in the relation of the Escabrosa (separated by conglomerate from the Pennsylvanian except in the extreme southeast) to the Redwall (underlying continental Permian strata and still unexplored in the Grand Canyon area), and in the interrelation of the Lower Mississippian stratigraphic units of Nevada, Utah, and Colorado, often with too generalized lists of index fossils which require critical paleontological studies. Separation of the Escabrosa (Kinderhook-Burlington) into zonal units and a comparative correlation with the Lower Mississippian of New Mexico, which contains larger assemblages of typical Mississippi Valley species, may contribute toward paleogeographic interpretation of the southwestern and interior seaways. Paradise formation of southeastern Arizona, most readily comparable paleontologically and stratigraphically to the standard Upper Mississippian of the Mississippi Valley, still has no other counterpart in the Southwest and is not easily traceable eastward through New Mexico. The southernmost outpost of the comparable western unit—the Brazer limestone—, with stratigraphically diffused paleontological indices and without Archimedes facies, is a long distance to the north, which postulates research problems for the intermediate stations, whereas the recent finds of Mississippian faunas in Sonora suggest the possibility of a southwestern orientation of a Late Mississippian passageway in common with the general direction of other Paleozoic and even Mesozoic outlets in that region.

SUBSURFACE CORRELATION OF LOWER CHESTER STRATA IN THE ILLINOIS BASIN

DAVID H. SWANN AND ELWOOD ATHERTON

Illinois Geological Survey, Urbana, Ill.

Cross sections and other data substantiate the following correlations. Big Clifty sandstone (currently called Cypress) of Kentucky and Indiana is subsurface "Jackson sand" and is equivalent to shale in middle to lower part of Golconda formation of Illinois. Indiana's Beech Creek limestone is Kentucky's uppermost Gasper limestone, Illinois' basal Golconda limestone, and subsurface "Barlow lime." Illinois' Cypress sandstone is Indiana's Elwren. Bethel sandstone of Kentucky and southeastern Illinois is equivalent to outcropping lower to middle Paint Creek shales and subsurface "Paint Creek stray," southwestern Illinois. Indiana's Beaver Bend limestone is "upper Renault (Downeys Bluff) limestone" of southeastern Illinois but is basal Paint Creek ("pink crinoidal") limestone of southwestern Illinois. Mooretown sandstone of Indiana, "middle Renault (Shetlerville) shale" of southeastern Illinois, the subsurface "Benoist" (currently "Bethel") sand of southwestern Illinois and at least part of the outcrop Yankeetown chert in southwestern Illinois are approximate correlates. Indiana's Paoli limestone is probably basal Shetlerville (Renault) limestone of southern Illinois outcrops. Both the outcrop Levias limestone and the basal Shetlerville are included in subsurface "lower Renault lime" of southeastern Illinois and possibly in "Renault lime, shale, and sand" of southwestern Illinois. In southeastern Illinois, outcrop Rosiclare sandstone is subsurface "Aux Vases sand"; outcrop upper Fredonia limestone is subsurface "Lower O'Hara" or "Levias"; outcrop Spar Mountain (sub-Rosiclare sandstone lentil in Fredonia) is subsurface "Rosiclare"; lower part of outcrop Fredonia equals entire subsurface "Fredonia" including "McClosky."

METHODS USED IN THE INVESTIGATION OF THE GLACIAL AQUIFER IN THE VALLEY OF MIDDLE BRANCH OF NIMISHILLEN CREEK NEAR CANTON, OHIO

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c/o U. S. Geological Survey, 553 E. Broad St., Columbus, Ohio

Canton now pumps an average of 8 million gallons a day from wells screened in the glacial gravels in the valley of Middle Branch of Nimishillen Creek. Current investigation will determine whether enough recharge is being rejected to the north of the present pumping to warrant further development of the ground-water supply in the valley.

The investigation has included (1) analysis of the flow-duration characteristics of Middle Branch in comparison with other near-by streams traversing areas of similar geology and topography, (2) determination of actual losses in stream flow caused by the municipal pumping, by gauging the stream flow with current meters at intervals along the stream, and (3) studies of the extent of the effect of the present pumping by means of a line of observation wells extending several miles north of the present well field.

Stream-flow records for Middle Branch show that the flow per unit of drainage area is consistently less than for other near-by streams which drain areas of similar geology and topography. The measurements of flow at intervals along the stream show that losses occur in varying amounts depending on the stage of the stream and of ground-water levels. Infiltration rates have varied from zero to over 3 million gallons a day per acre of stream bottom. At some periods as much as 33 per cent of the flow of the stream infiltrates into the aquifer. Profiles of the water table to the north of the well field show that ground-water levels at times are above stream level. When this condition exists during periods of high stream flow, potential recharge from the stream to the aquifer is rejected.

DUST-CLOUD THEORY OF PLANETARY EVOLUTION

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According to this theory the planets developed within a large cloud of interstellar dust and gas as it collapsed to form the sun. Beginning as minor condensations in a smaller cloud of the assembly, the planets grew in mass, spiralled inward, and gained rotational momentum by accretion of matter from the large cloud—until the collapse was complete.

Observational and theoretical aspects of the suggested process are discussed, with special emphasis on problems connected with the origin of the earth.

MISSISSIPPIAN-PENNSYLVANIAN BOUNDARY PROBLEMS IN THE ROCKY MOUNTAIN REGION

JAMES STEELE WILLIAMS

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In many places in the Rocky Mountain region where upper Mississippian rocks underlie Pennsylvanian rocks it is difficult to determine the precise location of the boundary. This is largely because (1) rocks of similar lithology occur on each side of the boundary; (2) frequently fossils are absent or too poorly preserved for certain identifications, and (3) where fossils are present, diagnostic species are rare, the common Mississippian invertebrate species being generalized forms that morphologically overlap common Pennsylvanian species. Unconformities not supported by fossil evidence are unreliable. Formations that in many areas straddle the boundary are generally very unsatisfactory even though it is possible to locate the boundary in some stratigraphic sections within these areas. Subsurface studies and other detailed stratigraphic work challenge long-held criteria for formations in the Rocky Mountain area.

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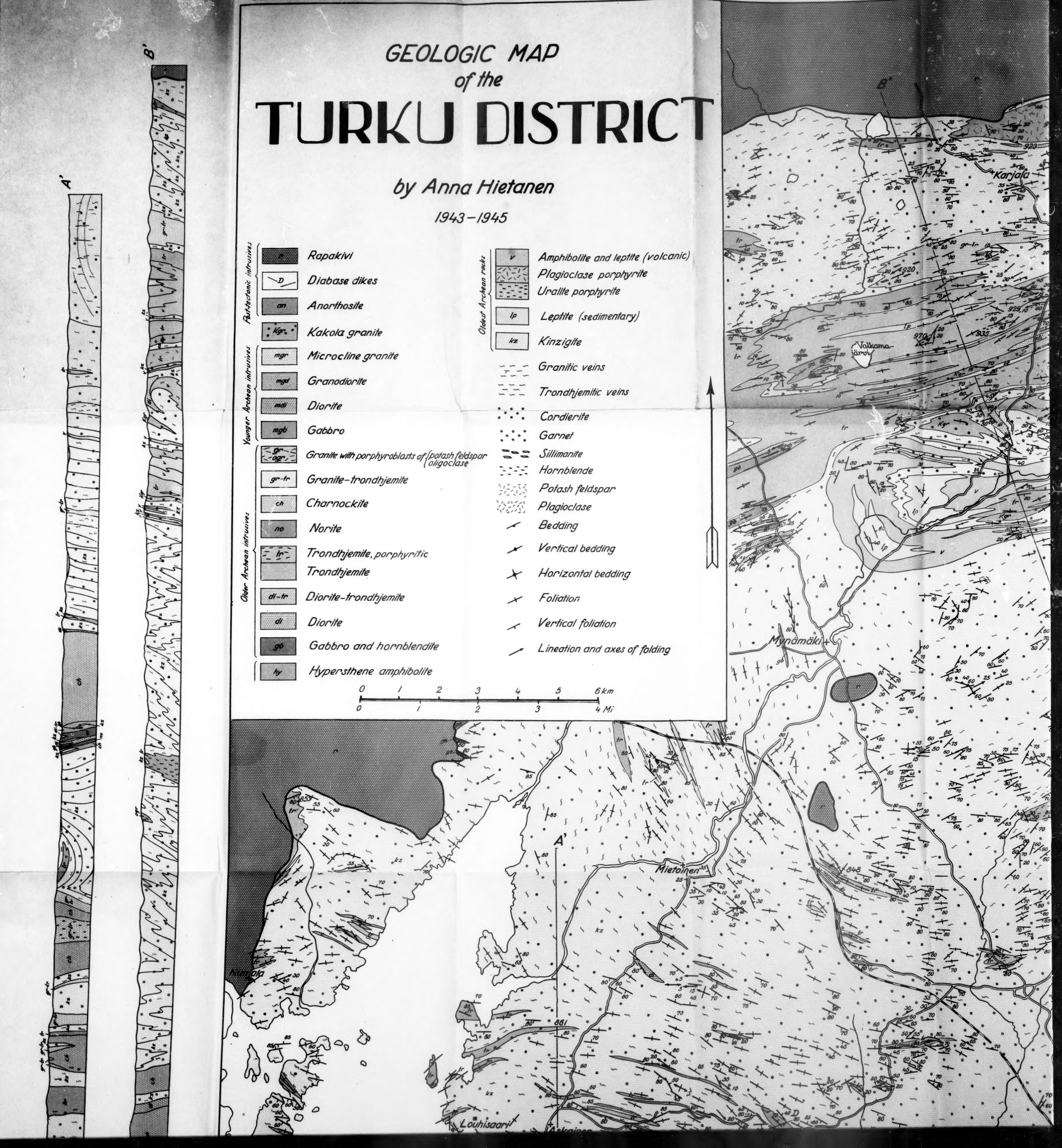


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GEOLOGIC MAP AND CROSS SECTIONS OF THE

OSS SECTIONS OF THE TURKU DISTRICT, SOUTHWESTERN FINLAND

Figure 1. Undeformed Carbonate Pebbles and Single Grains (White)
In matrix of crystalline carbonate, spherulitic oöids, mud pellets, clusters, and shaly bands. Note flowage around pebbles. Deformation 60 per cent. Quarter of a mile S. of Stoughstown, Pa. Newville quadrangle.

Figure 2. Odd-shaped Fossil Fragments Oriented Parallel to Bedding
Covered with radially growing carbonate. Oöids are few and irregularly distributed. Rose Hill (Silurian), Md. Lower McKenzie.

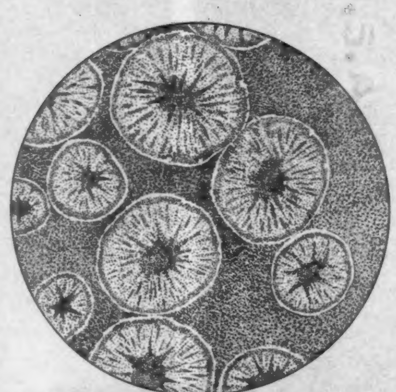


Figure 3. Spherulitic Undeformed Oölite in Muddy Matrix
With small growth rims (white), Mississippian. South end of Criner Hills, Okla.

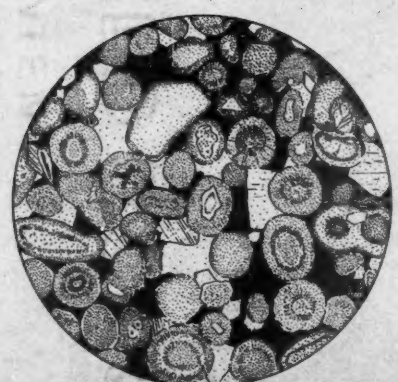


Figure 4. Unassorted Oölite, Undeformed with Crystallization of Carbonate and Pore Space (Black)
McKlusky oölite, Clay City, Ill.

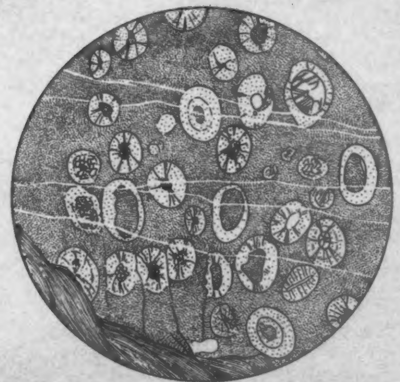


Figure 5. Oöids in Muddy Matrix without Growth Aprons
White lines are fractures normal *a*. *ac* section, spec. 203 B, deformation 30 per cent. Beekmantown (Ordovician) 2¼ miles SE. Greencastle, Pa., road to Leitersburg, Md.

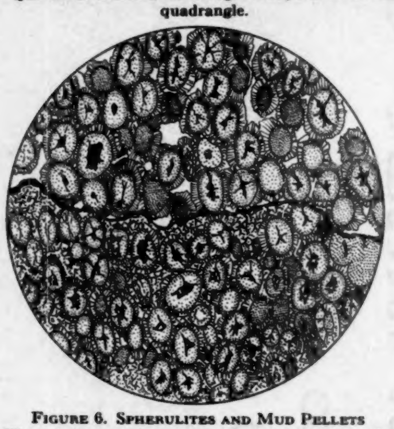


Figure 6. Spherulites and Mud Pellets
Elongated normal to bedding which becomes distinct through accumulation of mud (dark line). Matrix almost entirely made up of growth aprons on oöids. Elbrook limestone. Spec. 352, *ac* section, deformation 20 per cent. Three miles S.W. Shippensburg, Pennsylvania R.R. track.

Figure 7. Well-layered Spherulitic Oöids with Odd-shaped Centers of Quartz or Carbonate Grains
The shape of the center does not determine the shape of oöids. Bedding intense with stylolites. *ac* section, deformation 30 per cent. Spec. 245. Conococheague limestone, N. of Sharpsburg, Md.

Figure 8. Well-bedded Oölite with Odd Centers and Growth Aprons
Cleavage begins to form (top). Conococheague limestone, Landis Creek between Hagerstown and Boonsboro. Spec. 271. *ac* section, deformation 30 per cent.

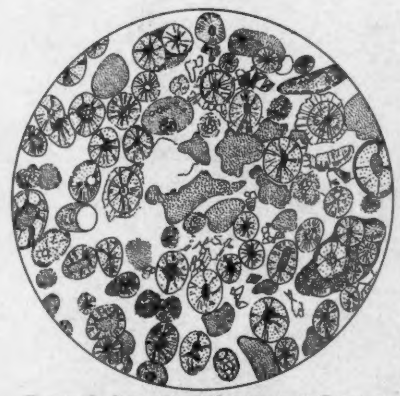


Figure 9. Spherulitic Oölite with Growth Aprons, Mud Pellets, and Oölite Pebbles
Matrix clear carbonate. Spec. 255, 10 per cent deformation. Two miles SSW. McConnelsburg, Pa.

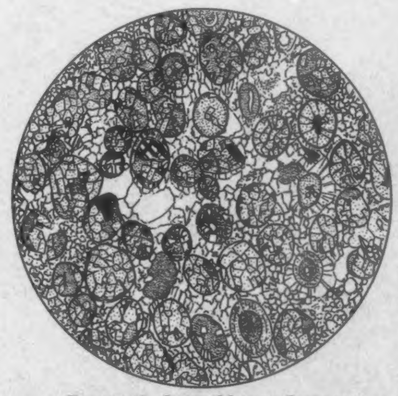


Figure 10. Oöids, Mostly Pebbles
Well rounded, undeformed but with growth aprons. Matrix crystalline and about same grain size. Spec. 256 A, half a mile S. of McConnelsburg, Pa.

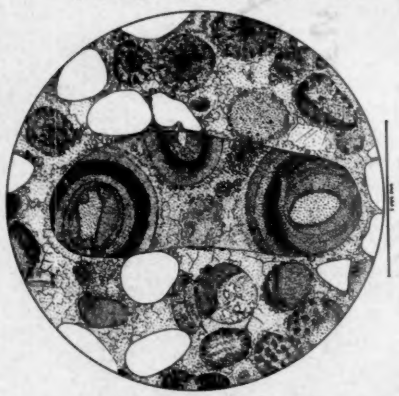


Figure 11. Unassorted Oölite with Mud Pellets, Fragments of Older Oöids, Small Oölite Pebbles and Sand Grains
Pore space filled with crystallized carbonate, undeformed. Bushberg formation, Columbia Missouri.

Figure 12. Mud Pellets and Layered Oöids in Crystalline Matrix
Deformed normal to bedding which is studded with quartz grains and much contorted. Spec. 332, Conococheague limestone, 3¼ miles S. Carlisle, Pa. *ac* section, deformation 40 per cent.

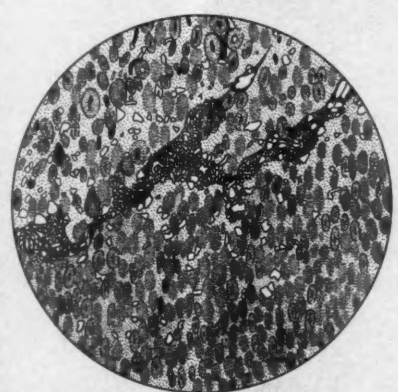


Figure 13. Spherulitic Oöids, Mud Pellets, and Angular Quartz Fragments
Spec. 350, Waynesboro formation, *a* equal *b*, deformation 30 per cent. Quarry a mile east of Waynesboro, Pa.

Figure 14. Intensely Deformed Shaly Limestone with Scattered Oöids and Contorted Bedding Plane
Deformation beyond measurement. Spec. 325, 3¼ miles southwest of Mechanicsburg, Pa.

Figure 15. Irregular Layered Mud Pellets in Clear Crystalline Matrix
Elongation becomes visible but irregular. St. Genevieve, Missouri.

CAMERA LUCIDA DRAWINGS OF FIFTEEN OÖLITES

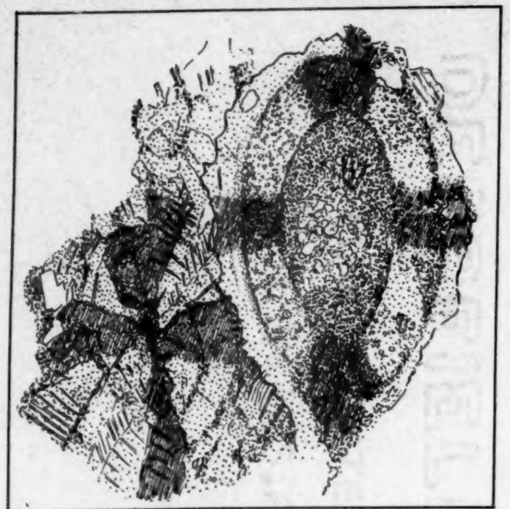


FIGURE 1. LAYERED SPHERULITE AND SPHERULITIC MUD PELLET.
Both show growth aprons beyond their original boundaries after deformation. Beekmantown (Ordovician). Paradise church 4½ miles NNE. center of Hagerstown. *ac* section, deformation 20 per cent, spec. 357, Hagerstown quadrangle.

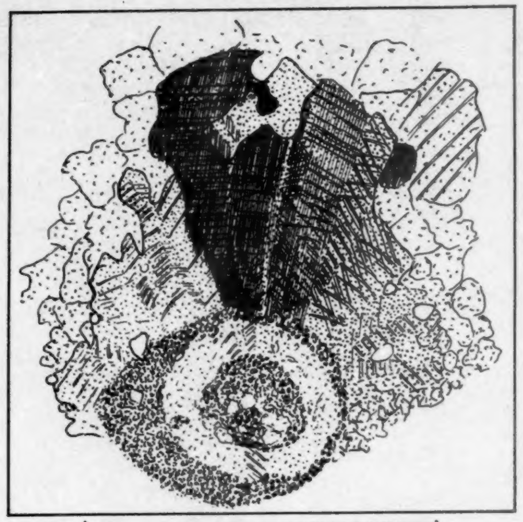


FIGURE 2. SPHERULITIC GROWTH AFTER DEFORMATION ON LAYERED OÖID
Beekmantown (Ordovician). Three miles ESE. Hagerstown on road from Chewsville to Funkstown. *ac* section, deformation 30 per cent, spec. 357, Hagerstown quadrangle.

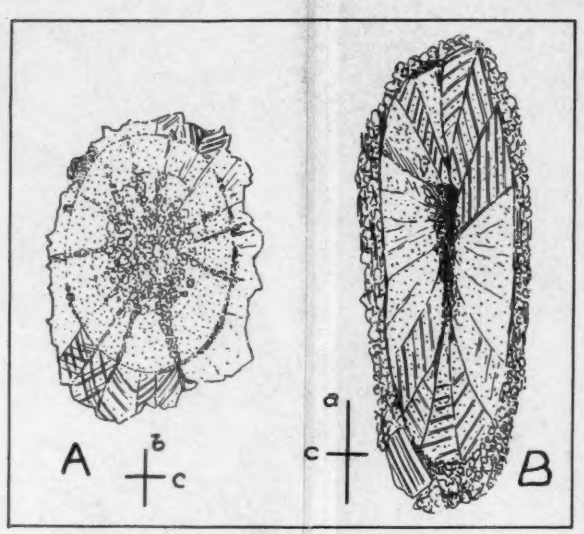


FIGURE 3. SPHERULITES IN LIMESTONE
A: *bc* view of spherulitic oöid. B: *ac* view of same specimen. Deformation in *bc* 20 per cent, in *ac* 70 per cent. Radial fractures and twinning indicate some consolidation of spherulite prior to deformation. Spec. 430, Conococheague limestone 1 mile SW. Downsville, Md.

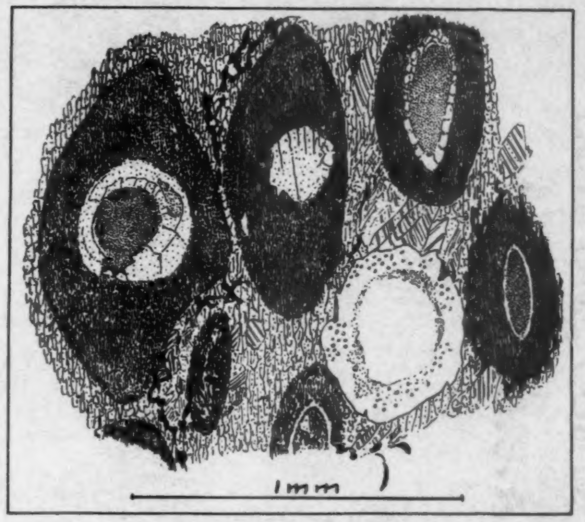


FIGURE 4. LAYERED MUD PELLETS WITH CRYSTALLINE AND SPHERULITIC CENTERS
Detrital quartz grain grew beyond its original limits which are still visible as a row of inclusions. Black material: iron oxide. Spec. 429, *a* equal *b*, *ac* cut, deformation 30 per cent. Conococheague Island 3¼ miles E. of Greencastle, Pa.

FIGURE 5. ELONGATE MUD PELLETS WITH CRYSTALLINE CENTERS IN MATRIX OF COARSELY CRYSTALLINE CARBONATE WITH TWINNED GRAINS
Fracture is healed by clear, undeformed calcite. Spec. 431, *ac* cut, *a* equal *b*, deformation 30 per cent. Beekmantown limestone, Spielman, Md.

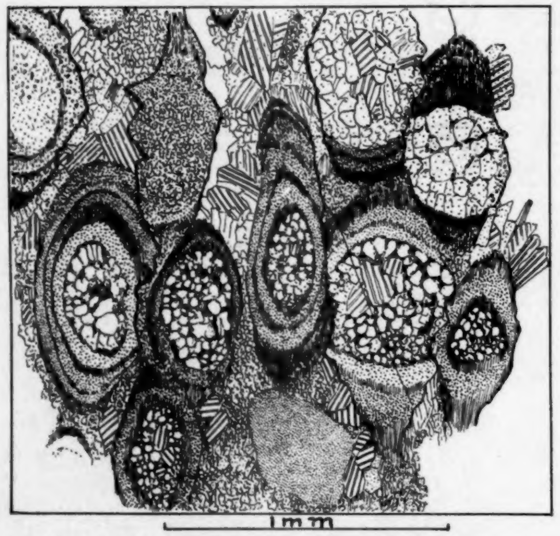


FIGURE 6. OÖIDS WITH CENTRAL CLUSTERS OF SMALL CARBONATE GRAINS AND SEVERAL LAYERS OF CARBONATE OR MUD
Cleavage parallels maximum elongation and solution has dissolved portions of oöids rendering measurements unreliable. Three and a half miles SE. of Stoughstown, Pa., on Shippensburg Carlisle road. Spec. 404.

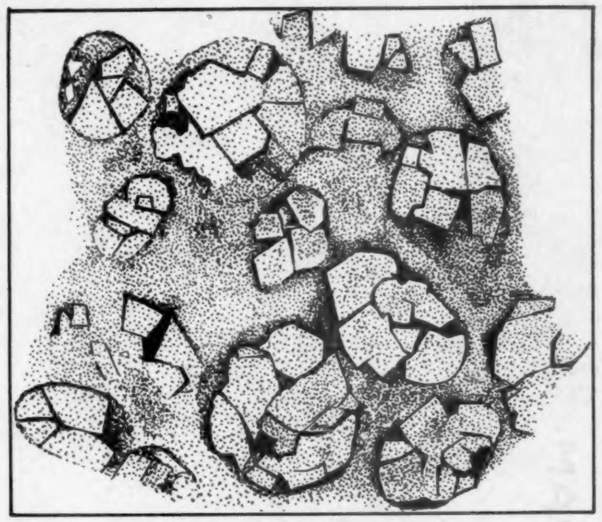


FIGURE 7. DETRITAL CLUSTERS OF CARBONATE (PROBABLY "PEBBLES")
In weathered outcrops they appear as yellow round grains resembling oölites. Spec. 417, 1¼ miles NE. little Georgetown, near Potomac River.

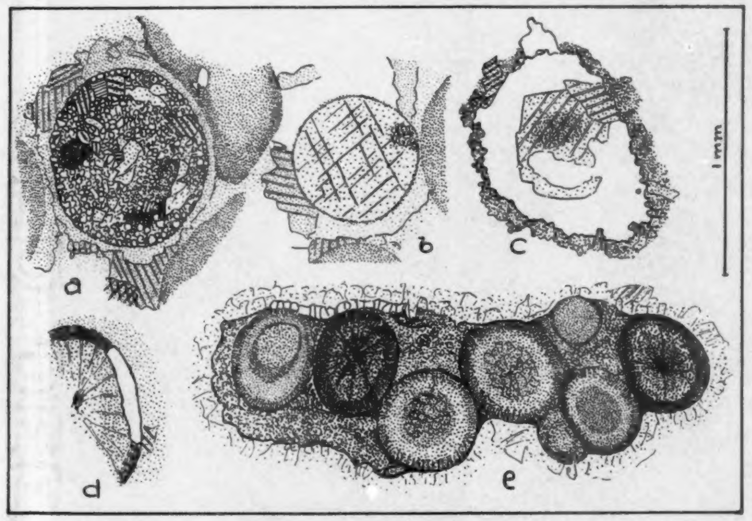


FIGURE 8. CONOCOCHEAGUE LIMESTONE
a: Well-rounded cluster of small carbonate crystals in matrix of mud pellets and newly grown carbonate. b: One well-rounded dolomite grain in matrix of secondary carbonate and spherical mud pellets. c: Chert replacing grain of carbonate. d: Chert replacing outer layer of an oöid. e: Larger pebble of oölite containing several well-layered oöids in muddy matrix. Calcite fringe grows on pebble in undisturbed, clear and larger grains. Three miles NW. Altenwald, center of Chambersburg quadrangle. Spec. 394.

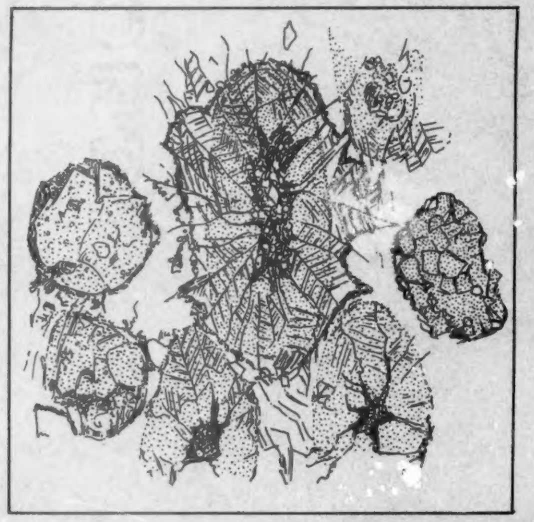


FIGURE 9. SPHERULITIC OÖLITES, DEFORMED AND ALIGNED
Growth aprons extend into matrix. At left two undeformed pebbles of dolomite. Spec. 436, *ac* section, deformation 30 per cent. Beekmantown, a mile west of Mercersville, Md.

FIGURE 10. SPHERULITES AND MUD PELLETS IN FINE SHALY MATRIX
With abundant quartz fragments. Growth aprons of clear, light carbonate in the direction of extension. Fracture across center of spherulite healed with fibrous carbonate. Center of large spherulite is calcite. Three miles SE. Greencastle. Spec. 385.

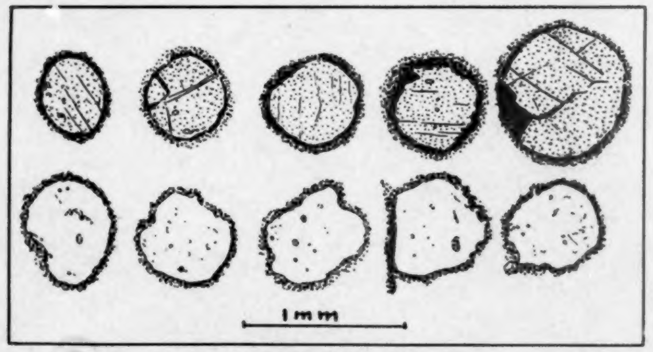


FIGURE 11. DETRITAL QUARTZ GRAINS
Light, in comparison with detrital carbonate grains of same order of magnitude and degree of roundness.

FIGURE 12. DETRITAL QUARTZ GRAINS IN SAME SLIDE AS FIGURE 11
With rim of newly growing quartz in same orientation of original grain and clearly indicating crystal shape.

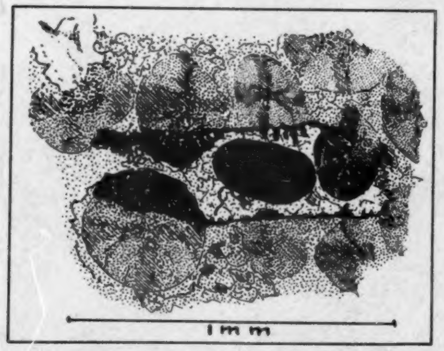


FIGURE 13. DETRITAL QUARTZ GRAIN
Growing into complete crystal by replacement of oöids rather than matrix. Spec. 288, Conococheague limestone, opposite Two Locks, Md.

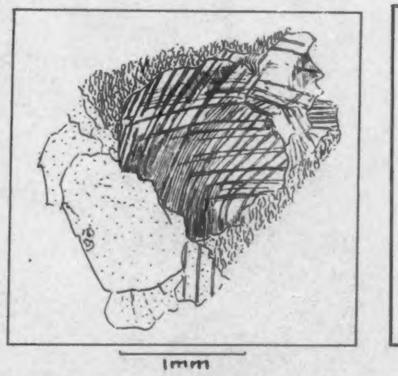


FIGURE 14. TWO GENERATIONS OF CALCITE
The older fracture filling shows twinning and fracturing, the later one transgresses it and is clear. Conococheague limestone. Spec. 360, White Hall school, 3 miles S. of Chewsville, Md.

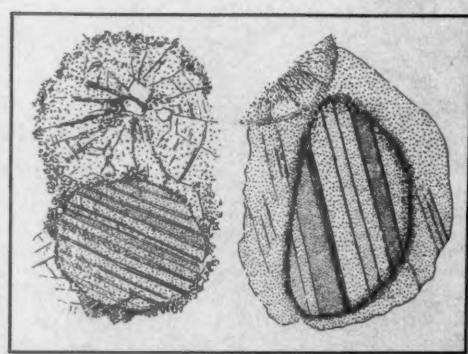
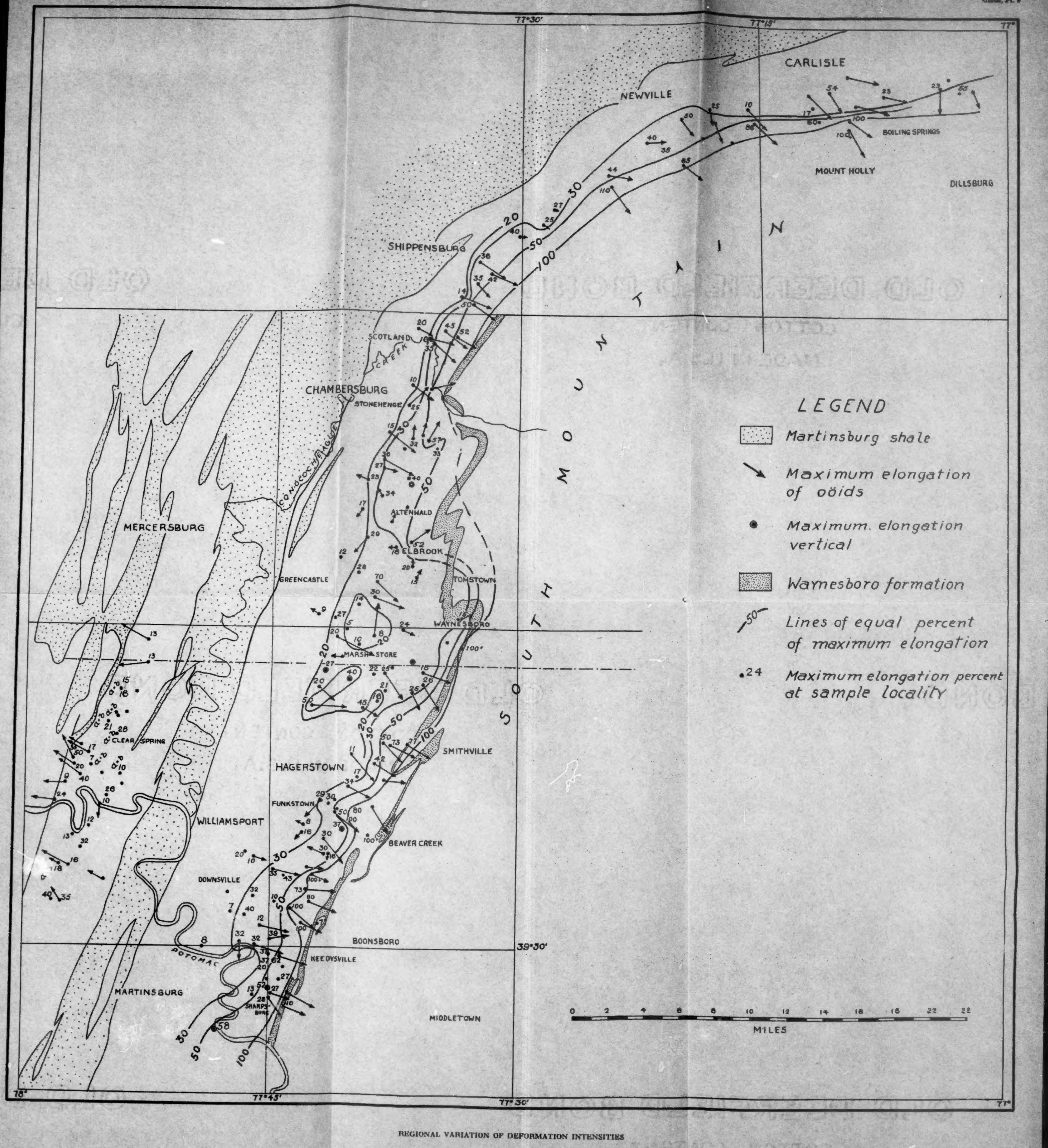
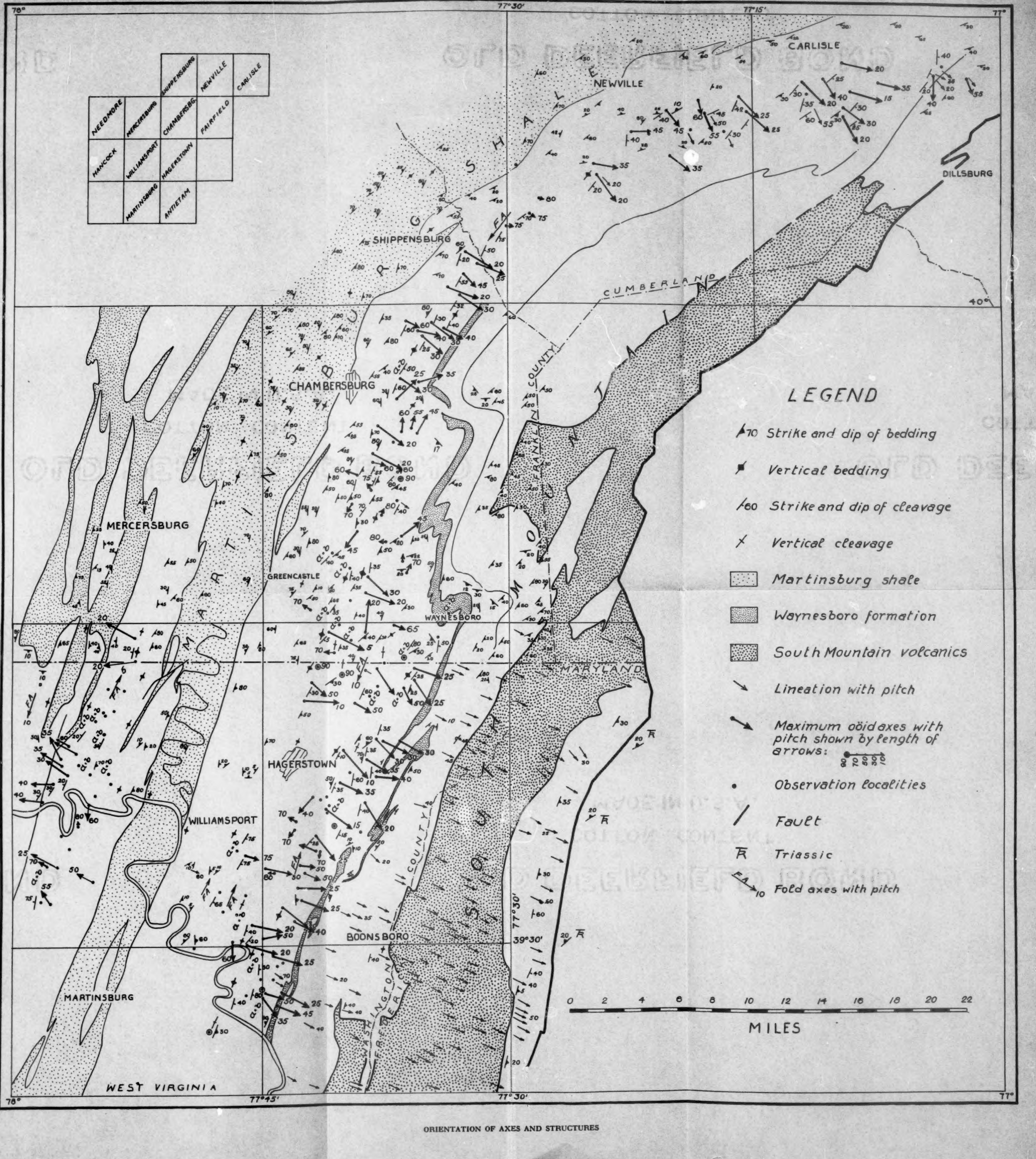


FIGURE 15. CALCITE GRAINS
Left: Spherulite and detrital calcite grains with twinning.
Right: Single calcite grain enlarged by secondary growth.

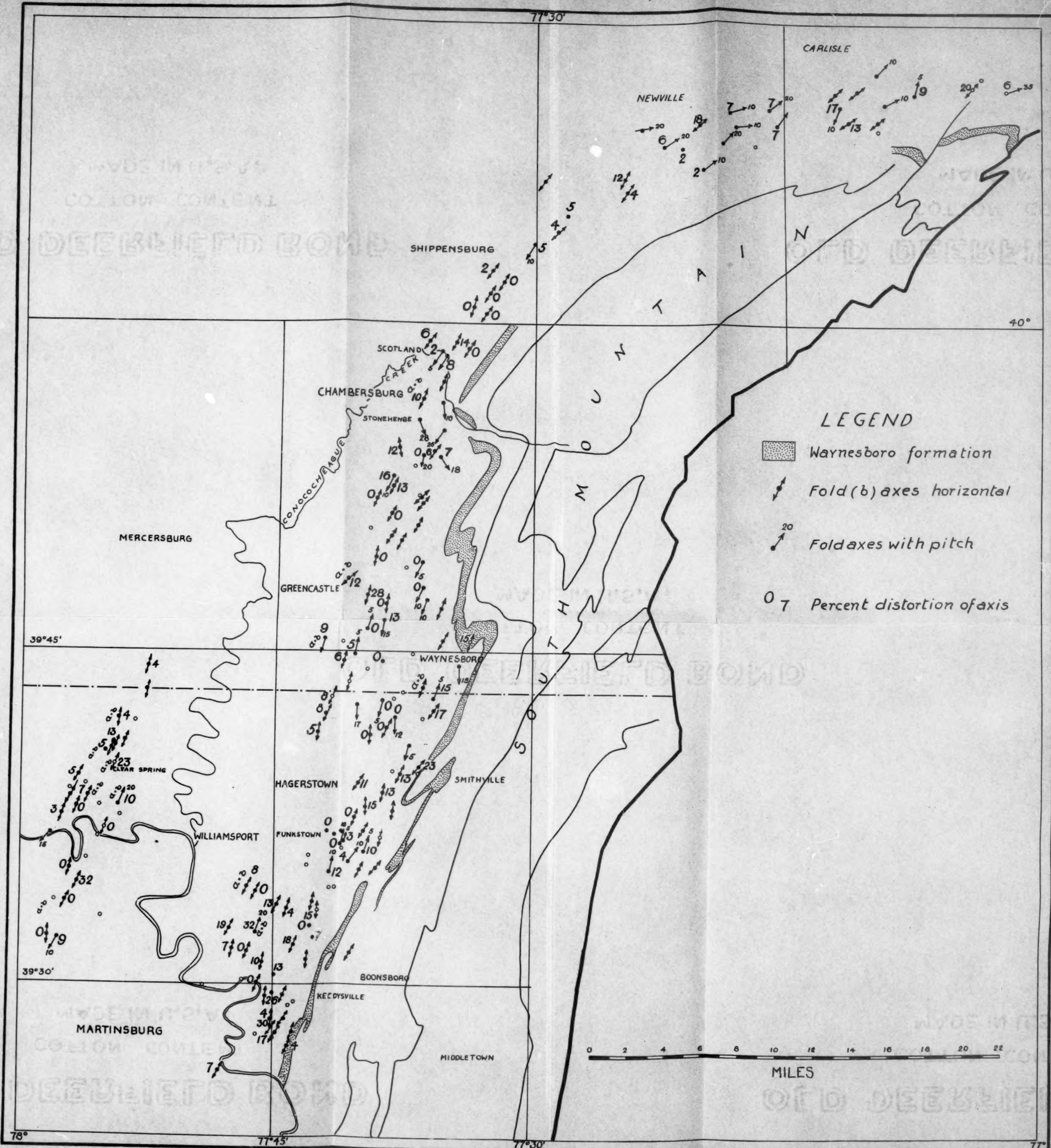
CAMERA LUCIDA DRAWINGS OF FIFTEEN OÖLITES



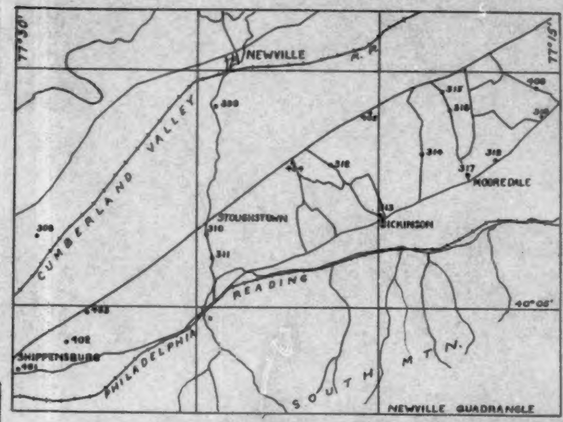
REGIONAL VARIATION OF DEFORMATION INTENSITIES

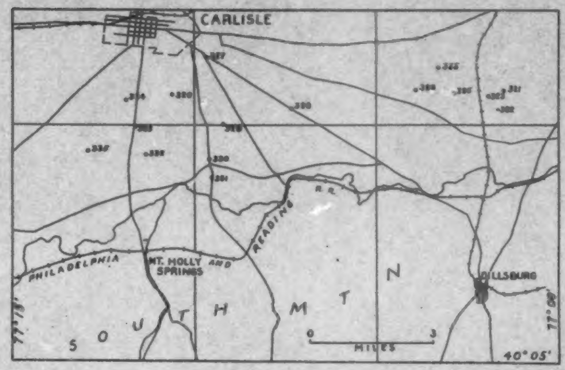


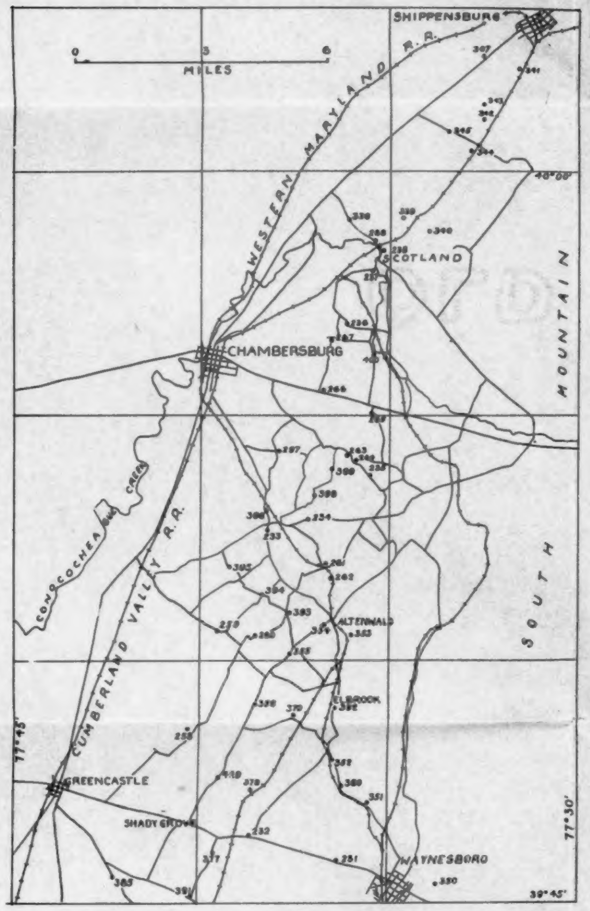
ORIENTATION OF AXES AND STRUCTURES

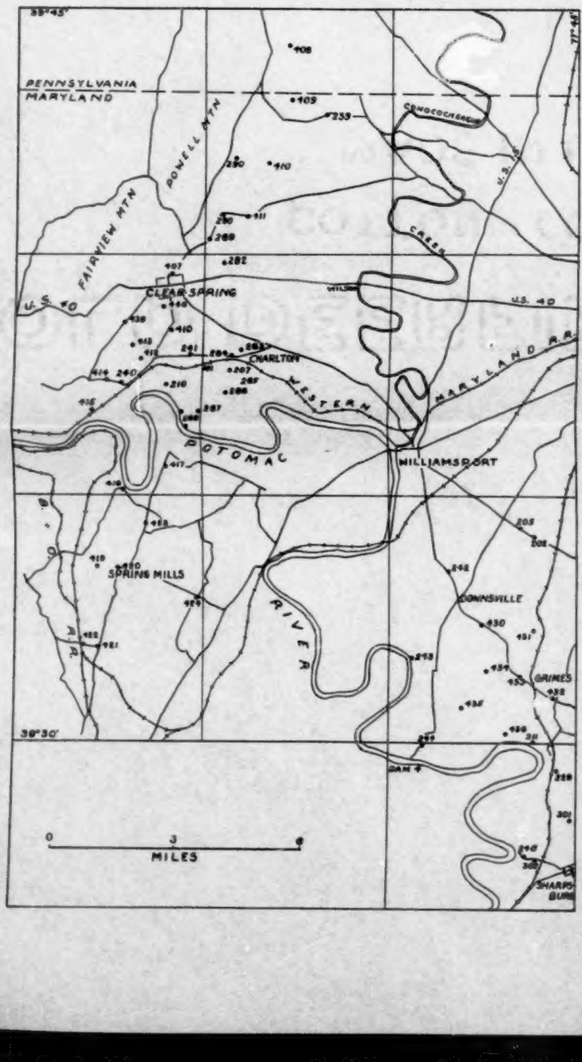


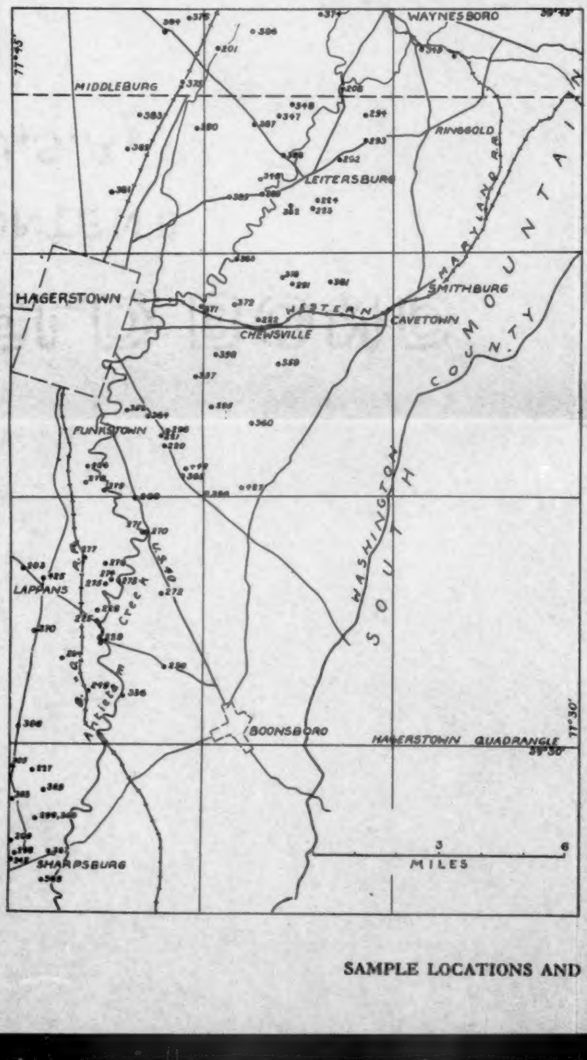
ORIENTATION OF FOLD AXES











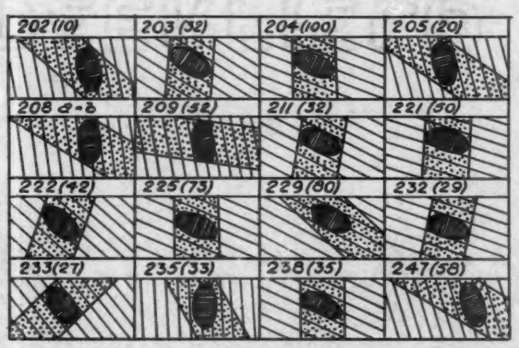


Figure 1

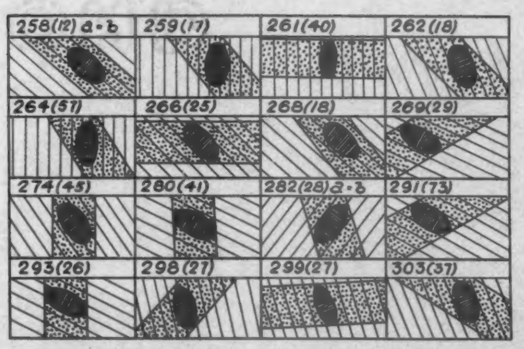


Figure 2

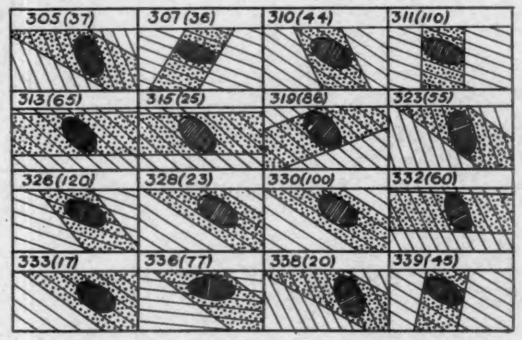


Figure 3

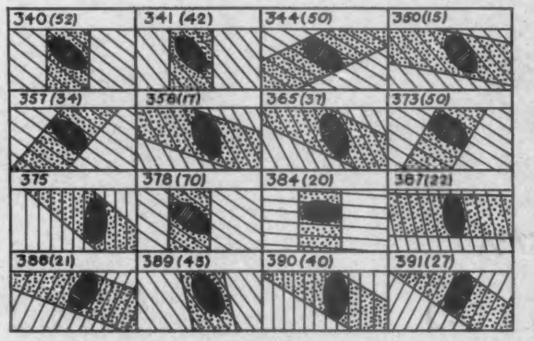


Figure 4

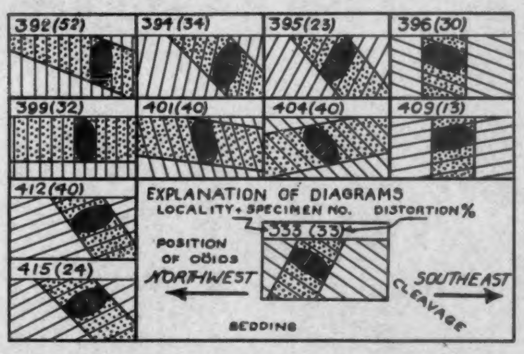
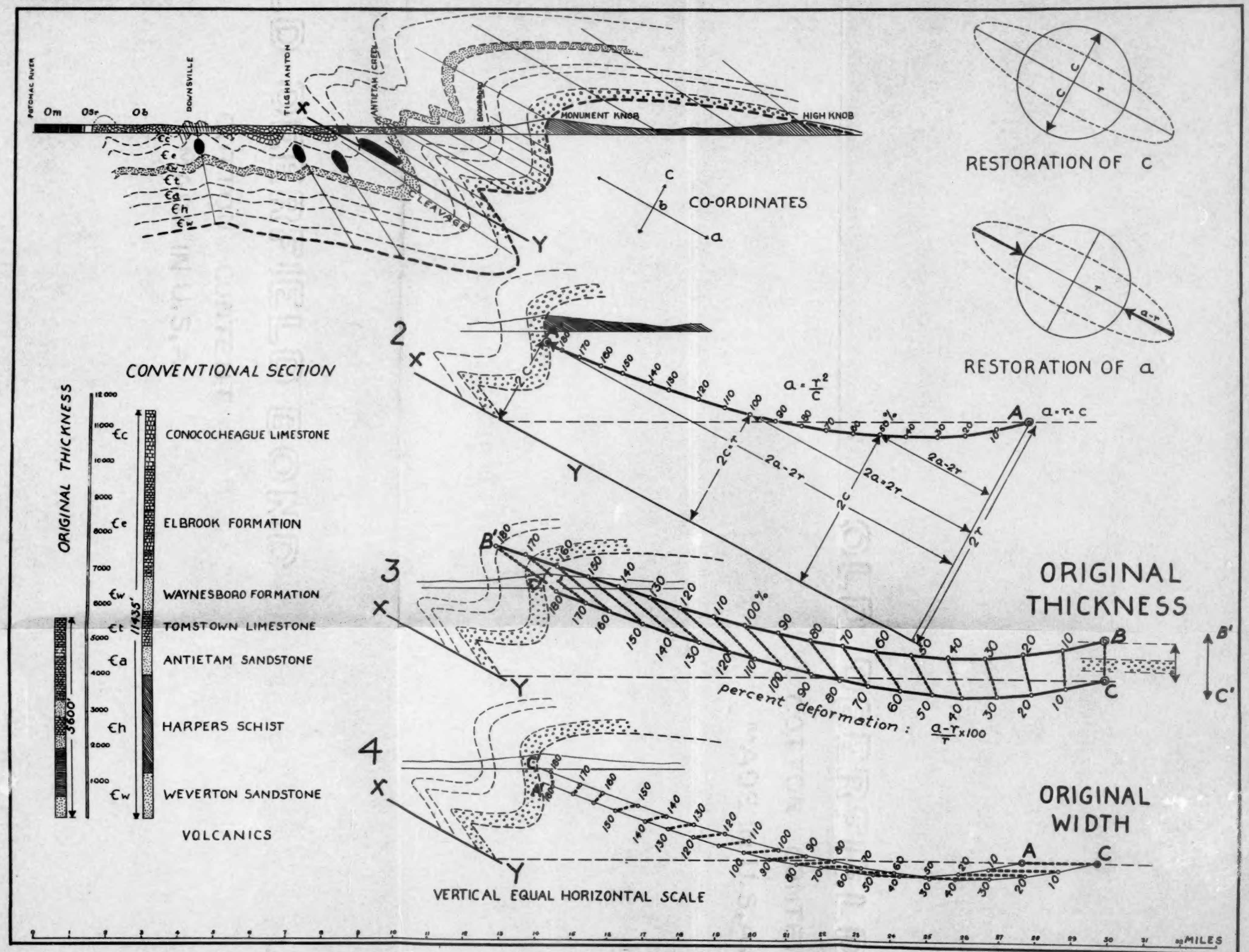


Figure 5

SAMPLE LOCATIONS AND OÖID ORIENTATIONS



CONSTRUCTION OF SHEAR FOLDS